CRC Report No. AVFL-17b

BIODIESEL AND RENEWABLE DIESEL CHARACTERIZATION AND TESTING IN MODERN LD DIESEL PASSENGER CARS AND TRUCKS

November 2014

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Final Report

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Biodiesel and Renewable Diesel Characterization and Testing in Modern LD Diesel Passenger Cars and Trucks

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Acknowledgments

The authors thank the following organizations and individuals for their valuable contributions to this project.

We acknowledge funding from Coordinating Research Council (CRC).

We thank the AVFL-17b program leaders Drs. Mani Natarajan and Garry Gunter from Marathon Petroleum Company LLC and Phillips 66 Company, respectively, for their technical guidance and support. We also thank the CRC AVFL-17b technical committee members for their guidance and advice during the course of this program. The authors greatly appreciate the in-kind vehicle contributions from Daimler, USA, Volkswagen Group of America, and BMW, USA for this program. The authors also thank Phillips 66 Company for performing in-kind detailed fuel properties analyses for all test fuels employed in this program.

We acknowledge Dr. Daniel Short, Ms. Diep Vu, and Dr. Maryam Hajbabaei for their valuable contribution in analyzing the data and performing the particle emissions testing for this program.

We acknowledge Mr. Mark Villela, Mr. Kurt Bumiller, and Mr. Joe Valdez, of the University of California, Riverside for their contributions in conducting the emissions testing for this program.

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Executive Summary

In recent years, government agencies around the world have implemented legislation that targets growing the use of renewable fuels in the transportation sector. In the U.S., the Energy Independence and Security Act of 2007 mandates the use of 36 billion gallons of biofuels in the transportation fuel market by 2022. The European Union (EU) has implemented several government mandates, such as the EU Renewable Energy Directive (2009/28/EC), which requires at least 10% (energy basis) of each Member State's transport fuel use to come from renewable sources (including biofuels). In California, the low carbon fuel standard (LCFS) was implemented in 2011 to promote the reduction of greenhouse gas emissions by targeting a 10% reduction in the carbon intensity of transportation fuels by 2020 (Farrell and Sperling, 2007). With the expectation that the diesel light-duty vehicle population will continue to increase in the U.S. market in the near future and the substantial increase in the U.S. production of biodiesel over the past three years (US EIA), the primary objective of this program is to characterize the impact of biodiesel blends from different feedstocks and a renewable diesel blend with different types of petroleum diesel fuels on the exhaust emissions from modern technology light-duty passenger cars and light-duty trucks.

A total of seven fuels were used in this study, including two reference fuels: a Federal Ultra Low Sulfur Diesel (ULSD) and a CARB ULSD. Three different fatty acid methyl esters (FAME) were selected: a methyl ester produced from soybean oil (SME), a waste cooking oil methyl ester (WCO), and a methyl ester produced from animal fat (AFME). A hydrogenated vegetable oil (HVO) renewable diesel was also used. The three FAME and one renewable diesel blendstocks were used to prepare four 20 vol% blends with the Federal ULSD. Only the WCO biodiesel was used to prepare a 20 vol% blend in the CARB ULSD.

This study evaluated five light-duty diesel cars and three trucks equipped with direct injection, common-rail diesel engines. These vehicles were all equipped with diesel particle filter (DPF) and selective catalytic reduction (SCR) aftertreatment systems.

Every vehicle/fuel combination was tested at least twice over the Federal Test Procedure (FTP) driving cycle. The test vehicles were preconditioned using a procedure that included multiple fuel drain and fills (to 40% of the fuel tank volume), a catalyst sulfur purge cycle, four coast downs (70 to 30 miles per hour), and finally an LA4 cycle. Emissions measurements were made for THC, NMHC, NO_x, CO, CO_2, CH_4, PM mass, and fuel economy. Measurements of unregulated emissions were also made for elemental carbon (EC) and organic carbon (OC) fracrions, real-time ammonia (NH_3) emissions, particle number (PN) emissions, real-time particle size distributions, polycyclic aromatic hydrocarbons (PAHs), and nitro-PAHs. Nitrogen oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O) were also measured for Vehicle #4 through Vehicle #8.

An ancillary investigation was performed on two of the test vehicles (Vehicle #1 and Vehicle #3) fueled with the Federal ULSD and Fed/SME-20 blend to evaluate emissions generated during a DPF regeneration event. The regeneration testing protocol included driving each vehicle on-road for approximately 160 miles (20 LA4-equivalents) to build up soot in the DPF. Regulated and unregulated emissions measurements were conducted over a double EPA Highway Fuel Economy Test (HWFET) cycle. A baseline double HWFET was also conducted on the Federal ULSD for each vehicle for comparison purposes.

The regulated emissions, carbon balance fuel economy, PM mass and PN emissions, and formaldehyde and acetaldehyde emissions were subjected to statistical analysis using the Mixed procedure in PC/SAS (Statistical Analysis System for Personal Computers) from SAS Institute, Inc. For pollutants where the Mixed model showed that there were statistically significant differences between test fuels for FTP weighted composite or individual cycle phases, additional pairwise comparisons were performed using a least significant difference test to determine the specific fuel pairs that were statistically different. Results were classified as statistically significant for $p \leq 0.05$ and marginally statistically significant for $0.05 < p \leq 0.1$. A summary of the FTP weighted composite results for which fuel pairs were found to be different at a statistically significant level is provided in Table ES-1. While each pairwise difference in Table ES-1 is statistically significant at the 95% or 90% level, it should be noted that this does not mean that there is a 95 or even 90% probability of all the listed differences being true simultaneously. Results reported here are for the test conditions used in this study (i.e., test fuels, vehicles, driving cycles). Other trends may be observed under different conditions.

Table ES-1: Summary of statistical comparisons for different fuels

NO_x LSM (g/mile)							THC LSM (g/mile)							NMHC LSM (g/mile)						
A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
0.066	0.075	0.071	0.070	0.074	0.073	0.071	0.040	0.032	0.039	0.034	0.038	0.035	0.033	0.018	0.013	0.019	0.014	0.019	0.013	0.014
NS							**B 18% lower than A** **G 16% lower than A** **C 19% higher than B** **E 17% higher than B** G 14% lower than C							**B 28% lower than A** **F 24% lower than A** G 20% lower than A **C 48% higher than B** **E 49% higher than B** **D 24% lower than C** **F 29% lower than C** **G 26% lower than C** **E 32% higher than C** **E 32% higher than D** **F 29% lower than E** **G 26% lower than E**						
CH_4 LSM (g/mile)							CO LSM (g/mile)							CO_2 LSM (g/mile)						
A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
0.021	0.021	0.021	0.021	0.020	0.023	0.020	0.164	0.114	0.172	0.139	0.159	0.144	0.134	460	462	469	463	470	459	462
F 15% higher than E							**B 31% lower than A** G 18% lower than A **C 52% higher than B** **D 22% higher than B** **E 40% higher than B** **F 26% higher than B** **D 19% lower than C** F 17% lower than C **G 22% lower than C**							**C 1.9% higher than A** **E 1.7% higher than A** **E 2.3% higher than B** **F 2.1% lower than C** **E 1.7% higher than D** **F 2.5% lower than E** **G 1.7% lower than E**						
FE LSM (miles/gallon)							Formaldehyde LSM (µg/mile)							Acetaldehyde (µg/mile)						
A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
0.039	0.040	0.040	0.040	0.041	0.040	0.041	4744	3227	5780	4986	5639	4384	4202	1543	943	1684	1440	1622	1509	1408
B 3.7% lower than A **C 4.2% lower than A** **D 4.2% lower than A** **E 4.6% lower than A** **F 2.8 % lower than A** **G 5.7% lower than A** **G 2.1% lower than B** **F 2.1% higher than E** **G 3.0% lower than F**							**B 32% lower than A** **C 79% higher than B** **D 54% higher than B** **E 75% higher than B**							**B 39% lower than A** **C 79% higher than B** **E 72% higher than B** **F 60% higher than B** D 53% higher than B						

Where: A= Fed ULSD; B=CARB ULSD; C=Fed/SME-20; D=Fed/AFME-20; E=Fed/WCO-20; F=Fed/HVO-20; and G=CARB/WCO-20
Bold values are statistically significant $p \leq 0.05$; *Underlined values are marginally statistically significant* $0.05 < p \leq 0.1$

The emissions from the eight modern technology light-duty diesel vehicles tested in this program showed fuel effects for some pollutants, but not for others. For the weighted THC emissions, the CARB ULSD showed statistically significant reductions compared to the Federal ULSD, while the biodiesel blends with Federal ULSD showed statistically significant increases compared to CARB ULSD. Although some general trends towards lower THC emissions were seen with the biodiesel blends, these results indicate that diesel fuels with lower aromatics and higher cetane number (like CARB ULSD) produce lower THC emissions than 20 vol% biodiesel blends with ULSD having higher aromatics and lower cetane number.

Analogous to THC, weighted NMHC emissions showed statistically significant reductions for CARB ULSD compared to Federal ULSD. The 20 vol% renewable diesel blend also showed statistically significantly lower NMHC emissions compared to Federal ULSD. Some FAME blends in Federal ULSD showed statistically significant increases in NMHC emissions compared to CARB ULSD. Statistically significant differences were also observed between biofuel pairs.

For weighted CO emissions, both the CARB ULSD and the CARB/WCO blend showed statistically significant reductions compared to Federal ULSD. The FAME and renewable diesel blends in Federal ULSD showed statistically significantly higher CO emissions compared to CARB ULSD.

CO_2 emissions showed a slight upward trend for the biodiesel blends. Statistically significant increases in CO_2 emissions were seen for the SME and WCO blends with Federal ULSD compared to both reference diesel fuels. Statistically significant trends were also seen between different fuel pairs for weighted CO_2 emissions, as well as for the cold-start, hot-running, and hot-start CO_2 emissions. Fuel economy, measured on a carbon balance basis, showed, in most cases, statistically significant decreases with CARB ULSD and with biofuel blends compared to Federal ULSD for all three FTP phases and for the weighted values.

NO_x emissions did not show any statistically significant fuel effect for the entire FTP cycle or the individual phases. NO, NO_2, and N_2O emissions were measured for Vehicles #4 through Vehicle #8 and no statistically significant fuel effects were observed. NO_2 was the predominant NO_x species for each of these vehicles with the exception of Vehicles #5 and #6. In these two vehicles, NO emissions were generally higher than the other test vehicles, and their NO levels followed a trend similar to their NO_x emission levels.

Similar to NO_x emissions, PM mass and PN emissions did not show any statistically significant differences between all seven test fuels. It should be noted that PM mass emissions for all eight vehicles were below 3 mg/mile. No statistically significant differences were observed in the EC/OC fractions, with EC being at zero or near zero levels for most vehicles and OC being the majority of the carbonaceous fraction of the PM. The absence of fuel trends for the nitrogen oxides and PM, OC, and EC was largely due to the presence of the SCR for reducing NO_x emissions and the DPF for reducing PM emissions, which which minimized the effect of fuel composition on these emissions.

Formaldehyde and acetaldehyde were the dominant aldehydes in the exhaust for all eight vehicles, with heavier aldehydes, aromatic aldehydes, and ketones being detected for some vehicles but in lesser amounts. For formaldehyde emissions, CARB ULSD showed statistically significant reductions compared to Federal ULSD, while the biodiesel blends exhibited statistically significant increases relative to CARB ULSD. Similar to formaldehyde, acetaldehyde emissions showed statistically significant reductions for CARB ULSD relative to

Federal diesel, while the biodiesel and the renewable diesel blends led to statistically significant increases in acetaldehyde emissions compared to CARB ULSD. In general, the increases in lower-molecular weight aldehydes with biodiesel can be ascribed to the higher oxygen content in the methyl ester molecule.

PAHs in the vehicle exhaust were dominated by lower and medium molecular weight compounds for all vehicle/fuel combinations, suggesting that these compounds were pyrolyzed from incomplete combustion of the fuel. Heavier PAHs also were found in the exhaust but in lesser amounts. Total gas-phase PAH emissions were found in significantly higher concentrations than their corresponding particle-phase PAHs. The largest contributors to the gas-phase PAHs were mainly the two-membered ring compounds and their ethyl- and methyl-substituted derivatives. The total PAH results for the biodiesel and renewable diesel blend did not show clear trends, with some increases and some decreases in total PAH emissions compared to the reference Federal and CARB ULSDs. The gas-phase nitro-PAHs were more abundant than particle-phase nitro-PAHs, with lighter compounds, such as 1-nitronaphthalene and methyl-substituted nitronaphthalenes, being the dominant nitrated compounds. The predominant species for the particle-phase nitro-PAHs were the nitronaphthalenes, nitrophenanthrenes, and 1-nitropyrene. The biodiesel and renewable diesel blends showed both increases and decreases in gas- and particle-phase nitro-PAH emissions.

For all eight vehicles, NH_3 emissions showed measurable concentrations especially for Vehicle #1 and Vehicle #2. NH_3 emission levels for Vehicle #1 were higher than those of all vehicles tested during the course of this program. For the majority of vehicles, NH_3 emissions were found to be at or near zero levels. In general, NH_3 emissions for all eight vehicles did not present any consistent fuel trends between the baseline ULSDs and the biofuel blends.

Emissions measured on Vehicle #1 and Vehicle #3 during DPF regeneration showed increases compared to the highway driving cycle without DPF regeneration. This tendency was seen on both vehicles for the Fed/SME-20 blend and to a lesser extent for the Federal ULSD. Increases in emissions for some pollutants were seen for the biodiesel blend compared to the Federal ULSD, including THC, CH_4, PN, black carbon, and formaldehyde for Vehicle #1, and THC, NMHC, CO, NO_x, CO_2, and formaldehyde for Vehicle #3. For Vehicle #3, the increase in total carbonyl emissions for the biodiesel blend during DPF regeneration was statistically significant. Particle size distributions during DPF regeneration for both vehicles were dominated by the production of nucleation mode particles with peaks at around 10 nm in diameter. For other pollutants, the biodiesel blends showed reductions in emissions relative to the Federal ULSD, including PAHs and gas-phase nitro-PAHs for Vehicle #1, and PM mass for Vehicle #3. Further analysis of the PAH results showed that the biodiesel blends increased the formation of 2-ring PAH species during regeneration testing relative to Federal ULSD. Certain nitrated species, which were nearly below detection limits during baseline testing, increased with biodiesel relative to Federal ULSD during tests that included DPF regeneration, suggesting that these species formed in the DPF. Ammonia emissions exhibited higher concentrations (NH_3 slip) with subsequent reductions in NO_x emission levels during DPF regenerations, suggesting that the SCR system enabled significant NO_x conversion over the course of these events. The NH_3 emissions exhibited similar behavior for both the Federal ULSD and Fed/SME-20 blend during DPF regeneration, indicating that emissions during regeneration were primarily a function of vehicle operation, and did not show strong sensitivity to fuel composition.

Acronyms and Abbreviations

ASTM…….	American Society for Testing and Materials
ANOVA…….	Analysis of Variance
CARB…….	California Air Resources Board
CE-CERT……	College of Engineering-Center for Environmental Research and Technology (University of California, Riverside)
CH_4……..	Methane
CO……	Carbon Monoxide
CO_2……..	Carbon Dioxide
CRC…….	Coordinating Research Council
CPC…….	Condensation Particle Counter
DNPH……..	2,4-Dinitrophenylhydrazine
DOC……	Diesel Oxidation Catalyst
DPF……..	Diesel Particulate Filter
ECU…….	Engine Control Unit
EC……	Elemental Carbon
EEPS……	Engine Exhaust Particle Sizer
EPA……..	Environmental Protection Agency
FAME……	Fatty Acid Methyl Ester
FTP……...	Federal Test Procedure
GC……	Gas Chromatograph
GHG…….	Greenhouse Gas
HPLC……...	High Performance Liquid Chromatograph
HWFET……	Highway Fuel Economy Test
g/mile……	Grams per mile
LDV…….	Light-Duty Vehicle
LDT……..	Light-Duty Truck
LNT……..	Lean NO_x Trap

Lpm……..	Liters per minute
MAAP……..	Multi-Angle Absorption Photometer
MPG……..	Miles per gallon
MPH……..	Miles per hour
ng/mile……...	Nano grams per mile
NH_3……...	Ammonia
nitro-PAHs……	Nitrated Polycyclic Aromatic Hydrocarbons
NMHC……..	Non-Methane Hydrocarbons
NO_x ……..	Nitrogen Oxides
NO……	Nitric Oxide
NO_2…….	Nitrogen Dioxide
N_2O…….	Nitrous Oxide
OBD……..	On-board Diagnostics
OC…….	Organic Carbon
PAHs…….	Polycyclic Aromatic Hydrocarbons
PC……..	Passenger Car
PDP-CVS……..	Positive Displacement Pump-Constant Volume Sampling
PM…….	Particulate Matter
PN……..	Particle Number
SCR……...	Selective Catalytic Reduction
SVOC……	Semi-Volatile Organic Compound
TDL……..	Tunable Diode Laser
THC……..	Total Hydrocarbons
TIGF…….	Teflon-Impregnated Glass Fiber
ULSD……	Ultra-low sulfur diesel
VERL……	Vehicle Emissions Research Laboratory

1. Introduction

The global energy map is changing, with potentially far-reaching consequences for energy markets and trade. Global energy demand is expected to grow by more than one-third over the period from 2010 to 2035 with China, India and the Middle East accounting for 60% of the increase (IEA, 2012). Although energy demand is not expected to rise significantly in Organization for Economic Co-operation and Development (OECD) countries, there is a pronounced shift in these countries away from oil, coal, and, in some countries, nuclear towards natural gas and renewable fuels (IEA, 2012). In the United States (U.S.), there is considerable interest in biodiesel because of its domestic and renewable origin, as well as its potential to reduce life-cycle emissions of greenhouse gases (GHG) (Shrake et al., 2010). Biodiesel, collectively known as fatty acid methyl esters (FAME), is a renewable transportation fuel consisting of long-chain alkyl esters, which contain two oxygen atoms per molecule. Biodiesel is generally produced by the transesterification process from vegetable oils, used cooking oils, and animal fats. Biodiesel has similar properties to middle distillate petroleum diesel, is free of sulfur and aromatic compounds, non-toxic, and readily biodegradable (Hoekman et al., 2011; Lapuerta et al., 2008a).

Regulations are a main driver for biofuels development. The European Union (EU) directive on renewable energy (2009/28/EC) stipulates that each member state has to ensure that 10% of the fuel for the transport sector is biofuel or renewable electricity in 2020. Furthermore, the EU fuels quality directive already allows an increase of biodiesel content in diesel to 7% (B7) by volume. In the U.S., the EPA Renewable Fuel Standard version 2 (EPA-RFS2) and the California Low Carbon Fuel Standard (CA-LCFS), a state-enacted policy to reduce GHG emissions from motor vehicles, are driving the U.S. biofuels market. The EPA-RFS2 requires that 36 billion gallons of renewable fuel be available in the U.S. market by 2022. Although over the next several years ethanol is expected to make up the majority of this requirement, biodiesel and renewable diesel formulations are expected to have the largest penetration into the diesel fuel market. Unlike most European countries where diesel vehicle sales make up more than half of the new automobile market, the penetration rate for light-duty diesel vehicles in the U.S. is much lower due to lower gasoline prices and more stringent regulatory standards that reduce the attractiveness of diesel vehicles. However, because of their greater efficiency compared to conventional gasoline vehicles, light-duty diesel vehicles could become an important component of automaker strategies to meet rising U.S. Corporate Average Fuel Economy (CAFE) requirements. Some automotive manufacturers are currently offering diesel versions of some existing models in the U.S. market. These modern light-duty diesel vehicles incorporate a combination of engine design optimization and exhaust aftertreatment devices, including diesel particle filters (DPFs) for particulate matter (PM) and selective catalytic reduction (SCR) for nitrogen oxide (NO_x), to achieve the significant reductions needed to meet the current and upcoming U.S. standards (Wallington et al., 2013).

The effects of biodiesel usage on vehicle emissions have been investigated by various groups within the academic, commercial and regulatory communities. Many studies have reported that emissions of carbon monoxide (CO) total hydrocarbons (THC), and PM can be reduced with the addition of biodiesel, although an increase in NO_x emissions is usually acknowledged (Durbin et al., 2007; Lapuerta et al., 2008a; Giakoumis et al., 2012; Hoekman and Robbins, 2012). The majority of these studies have been conducted on heavy-duty and, generally, older technology engines (McCormick et al., 2001). Only a few studies are available on modern light-duty (LD) diesel vehicles, employing common-rail engine systems and aftertreatment technologies (Martini et al., 2007; Bannister et al., 2010; Rose et al., 2010; Karavalakis et al., 2010a; Macor et al.,

2011; Nikanjam et al., 2011). There also is a gap in the literature regarding the effect of biodiesel on unregulated pollutants. Several studies have reported an increase in carbonyl emissions (aldehydes and ketones) with the use of biodiesel blends, as a consequence of the oxygen content in the methyl ester molecule (Correa and Arbilla, 2008; Fontaras et al., 2009; Fontaras et al., 2010a Cahill and Okamoto, 2012). In addition, most authors have observed some decreases in emissions of polycyclic aromatic hydrocarbons (PAH) and their nitrated derivatives (nitro-PAH) when using biodiesel (Bagley et al., 1998; Yang et al., 2007; Macor et al., 2011; Surawski et al., 2011). However, the effect of biodiesel source material on PAH and nitro-PAH emissions is less clear, since there are a number of vehicle studies showing some increase in light molecular-weight PAH compounds with biodiesel (Karavalakis et al., 2010a; Karavalakis et., 2010b). Similar to toxic PAH compounds, information in the literature on particle number (PN) emissions and particle size distributions (PSDs) from biodiesel vehicles is limited and inconsistent. Increased PN emissions and lower size particles are generally but not always observed, and the reasons for such inconsistencies are not properly understood (Fontaras et al., 2009; Fontaras et al., 2010b).

The available literature, including CRC AVFL-17 (Hoekman et al., 2009) and CRC AVFL-17a (Hoekman et al., 2011) studies, have shown that the emissions results from late model vehicles/engines equipped with NO_x emission control catalysts, such as SCR or lean NO_x traps (LNT) are limited. With the diesel vehicle fleet turning over to much lower emitting vehicles, the University of California, Riverside's College of Engineering-Center for Environmental Research and Technology (CE-CERT) and the Coordinating Research Council (CRC) have undertaken a comprehensive study, which aims specifically at understanding the effects of different biodiesel blends and renewable diesel blends on regulated and selected unregulated exhaust emissions from modern technology light-duty passenger cars and light-duty trucks. The resulting study was termed the 'CRC AVFL – 17b' program. This study included emissions testing on eight light-duty diesel vehicles with seven different fuels, including both Federal and California ultra-low sulfur diesel, and five 20% biodiesel and renewable diesel blends. This report presents the results of this study and its implications in terms of the broader literature.

2. Experimental Procedures

2.1 Test Fuels

A total of seven fuels were used in this study. A Federal Ultra Low Sulfur Diesel (ULSD) and a CARB ULSD were used as the baseline fuels. The Federal ULSD was supplied from Chevron's Refinery in Pascagoula, MS, and had properties typical of those found in most automotive diesel fuels across the country. The CARB ULSD was supplied from BP's Vinvale Terminal in Southgate, CA, and had properties typical of diesel fuels used in California, which has specifications more stringent than those of Federal ULSD.

Three fatty acid methyl esters were used as blendstocks with the baseline diesel fuels. A methyl ester produced from soybean oil (SME), a waste cooking oil methyl ester (WCO), and a methyl ester produced from animal fat (AFME). The soy-based biodiesel was selected because soybean oil is the dominant oil produced in the U.S., and the development of biodiesel in the U.S. has focused around this type of feedstock. Both the waste cooking oil and the animal fat feedstocks are considered to be low-cost and low environmental impact feedstocks, and are characterized as CO_2 neutral. In addition, the animal fat biodiesel was selected since it is comprised of more saturated molecules and has less tendency to increase NO_x emissions compared to other feedstocks (Knothe, 2008). The soy-based biodiesel was supplied by Community Fuels, CA, the waste cooking oil biodiesel was supplied by Imperial Western Products, CA, and the animal fat biodiesel was donated by Renewable Energy Group, TX. All three producers were BQ9000 accredited certified. All neat biodiesel fuels were treated with commercial synthetic antioxidant additives to delay the onset of oxidation in the fuel and prevent degradation products that could cause engine and injector problems. The treat rate for the soy-based biodiesel was 1000 ppm of Nalco EC 5300 A additive. For the waste cooking oil biodiesel, the treat rate was 500 ppm of Albermarle Ethanox 4760r additive. For the animal fat biodiesel, the treat rate was 60 ppm of Eastman BioExtend™ 30 Antioxidant Solution. The main physicochemical parameters of the neat biodiesels are listed in Table 2.1.

Table 2-1: Properties of the neat methyl esters

Property	Method	SME	AFME	WCO
Sulfur (ppm)	D5453	0.6	5.4	13.55
Cloud Point (ºF)	D5773	32.9	58.3	37.7
Cetane Number	D613	49.19	67.06	58.05
Derived Cetane Number (IQT)	D6890	49.45	65.37	61.56
Ignition delay (ms)		4.148	3.105	3.267
CFPP (ºC)	D6371	-4	10	-2
CHNS by combustion (wt%)	D529			
C (wt%)		77.38	75.02	76.74
H (wt%)		11.66	11.54	11.75
N (wt%)		<0.15	< 0.75	<0.15
S (wt%)		<0.40		<0.40
Density by Digital Density Meter (API Gravity) at 60 ºF	D4052			
API Gravity		28.23	30.26	28.18
Density (g/ml)		0.8850	0.8739	0.8852
Flash Point by Pensky-Martins Closed Cup (ºF)	D93	>300	302	>300
Viscosity by Capillary Viscometer (mm^2/s at 40ºC)	D445	4.068	4.662	4.765
Lubricity by HFRR @ 60 ºC (microns)	D6079	178	211	179.5
Iodine Number (g Iodine/100 g)	EN1411	128	51	100
Oxygen by Atomic Emission Detection w/ extraction prep	GC-AED-O w/ prep	14.17	14.96	14.37
Ester Content (wt%)	EN14103	98.9	99.2	94.0
Linolenic acid methyl ester (wt%)	EN14103	7.8	<1.0	3.2
Free glycerin (wt%)	D6584	< 0.005	< 0.005	< 0.005
Monoglycerides (wt%)	D6584	0.274	0.263	0.55
Diglycerides (wt%)	D6584	0.130	< 0.050	0.139
Triglycerides (wt%)	D6584	0.089	< 0.050	< 0.050
Total glycerin (wt%)	D6584	0.100	0.077	0.165
Water by Karl Fischer Titration (ppm)	D6304	277	832	444
Oxidation Stability (hours)	EN14112	7.9	5.5	3.0
Total Acid Number (mg KOH/g)	D664	0.21	0.44	0.41
BTU Gross and Net by Bomb Calorimeter (Btu/lb)	D240			
BTU Gross (Btu/lb)		17,158	17,165	17,102
BTU Net (Btu/lb)		16,094	16,050	16,030
Na+K (wt ppm)	ICP-AES	<1, <1.7	<1.0	1.6, <1.7
Ca+Mg (wt ppm)		<0.7, <0.7	<0.7, <0.7	<0.7, <0.7
P (wt ppm)		<0.7	<1.1	<0.7

In addition to the methyl ester fuels, a renewable diesel fuel was also employed in this study. This fuel, supplied from Neste Oil, Espoo, Finland, is an HVO (hydrogenated vegetable oil)-type fuel that is paraffinic in nature. HVO is characterized by a higher cetane number compared to regular diesel fuel, its free of sulfur and aromatic compounds, and can be produced with a cloud point close to -40 ºC. However, it has poorer lubrication properties and lower volumetric energy content than regular diesel fuel (Hartikka et al., 2012). Although HVO is a renewable biofuel, it differs from methyl esters because the fatty acid feedstocks are hydrotreated to remove oxygen and to eventually produce a pure hydrocarbon fuel. The main properties of the renewable diesel are shown in Table 2.2. Additional analysis has been performed to determine the metals content in the renewable diesel.

Table 2-2: Properties of the renewable diesel fuel

Property	Method	Renewable Diesel
Hydrocarbon Types by Fluorescent Indicator Absorption (FIA)	D1319	
Aromatics (vol%)		< 5.0
Olefins (vol%)		0.8
Saturates (vol%)		> 95.0
Aromatics by Supercritical Fluid Chromatography (SFC) (area% equiv to wt%)	D5186	
1 Ring Aromatics (area% equiv to wt%)		0.00
2 Ring Aromatics (area% equiv to wt%)		0.00
3+ Ring Aromatics (area% equiv to wt%)		0.00
Non-Aromatics (area% equiv to wt%)		100.00
Total Aromatics (area% equiv to wt%)		0.00
Sulfur in HC by Oxidative Combustion and Ultraviolet Fluorescence (UVF)	D5453	
ppm		0.4
Oxygen by Atomic Emission Detection w/ extraction prep	GC-AED-O w/ prep	0.01
FAME content (wt%)		< 0.05
Range		A
Water by Karl Fischer Titration (ppm)	D6304	14
Metals by Inductively Coupled Plasma Mass Spectrometry (ppm)	ICP-MS	
V 51 (wtppm)		0.010
Cr 52 (wtppm)		0.005
Fe 56 (wtppm)		0.216
Co 59 (wtppm)		< 0.005
Ni 60 (wtppm)		< 0.005
Cu 63 (wtppm)		0.016
Zn 66 (wtppm)		0.226
As 75 (wtppm)		<0.005
Se 78 (wtppm)		<0.005
Ag 107 (wtppm)		< 0.005
Cd 111 (wtppm)		< 0.005
Sn 118 (wtppm)		0.153
Sb 121 (wtppm)		< 0.005
Ba 138 (wtppm)		< 0.005
Metals by Inductively Coupled Plasma Atomic Emission Spect (ppm)	ICP-AES	
Al (wtppm)		< 0.6
Ba (wtppm)		< 1.1
Ca (wtppm)		< 0.7
Cd (wtppm)		< 0.6
Cr (wtppm)		< 0.9
Cu (wtppm)		< 1.1
Fe (wtppm)		< 1.1
Mg (wtppm)		< 0.7
Mn (wtppm)		< 0.6
Mo (wtppm)		< 0.9
Na (wtppm)		< 1.0
Ni (wtppm)		< 1.1
P (wtppm)		< 1.1
S (wtppm)		< 100
Si (wtppm)		< 0.6
Ti (wtppm)		< 0.9
V (wtppm)		< 1.1
Zn (wtppm)		< 0.7
Distillation	D86	
IBP (F)		334.8
T05 (F)		401.2
T10 (F)		441.5

Table 2-2: Properties of the renewable diesel fuel (Continued)		
Property	**Method**	**Renewable Diesel**
T20 (F)		479.1
T30 (F)		503.1
T40 (F)		516.4
T50 (F)		524.1
T60 (F)		529.7
T70 (F)		535.5
T80 (F)		541.9
T90 (F)		550.9
T95 (F)		558.1
FBP (F)		574.2
Recovery (%)		97.6
Residue (%)		1.5
Loss (%)		0.9
E200 (ml)		0.0
E300 (ml)		0.0
Flash Point by Pensky-Martins Closed Cup	D93	149
CHNS by combustion (wt%)	D5291	
C (wt%)		85.07
H (wt%)		14.87
N (wt%)		< 0.15
S (wt%)		< 0.40
Total (wt%)		99.94
BTU Gross and Net by Bomb Calorimeter (Btu/lb)	D240	
BTU Gross (Btu/lb)		20,320
BTU Net (Btu/lb)		18,964
Cetane Number by Engine	D613	76.15
Derived Cetane Number by IQT	D6890	
Derived Cetane Number		72.86
Ignition Delay (ms)		2.851
Density by Digital Density Meter (API Gravity) at 60F	D4052	
API Gravity		50.97
Density (g/ml)		0.7747
Viscosity by Capillary Viscometer (mm^2/s at 40ºC)	D445	2.483
Lubricity by HFRR at 60ºC (microns)	D6079	422.0
Cloud Point by Constant Cooling Rate (ºC)	D5773	-24.0
Cold Filter Plugging Point (CFPP), (ºC)	D6371	-26.0

All three methyl esters and the renewable diesel were used to create blends with the Federal ULSD at a proportion of 20% by volume. For the CARB ULSD, only the waste cooking oil biodiesel was used to prepare blends at 20% by volume. Blends are labeled with diesel fuel, followed by the biodiesel and biodiesel concentration. For example, Fed/SME-20 denotes Federal ULSD containing soy-based biodiesel at 20 volume percent. The main properties of the reference ULSD fuels and associated test methods are provided in Table 2.3. Additional analyses were conducted to evaluate the metals content in the ULSD fuels. Table 2.3 also shows the basic properties of the biodiesel and the renewable diesel blends.

The drums used to store the neat biodiesels and their blends with the diesel fuels were nitrogen-purged, blanketed, and stored in an area protected from sunlight and rain at CE-CERT.

Table 2-3: Properties of the reference ULSD fuels, the biodiesel, and the renewable diesel blends

Property	Method	Federal ULSD	Fed/ SME-20	Fed/ AFME-20	Fed/ WCO-20	Fed/ HVO-20	CARB ULSD	CARB/ WCO-20
Sulfur in HC by Oxidative Combustion and Ultraviolet Fluorescence (UVF), ppm	D5453	7.9	6	6.63	6.14	5.75	9.9	9.8
Cloud Point (ºF)	D5773	3.7	10.9	27	11.5	1.3	19.9	21.6
Cetane Number	D613	44.21	45.89	49.32	46.99	51.85	57.54	56.85
Derived Cetane Number by IQT	D6890							
Derived Cetane Number		45.36	45.67	49.76	47.88	50.86	54.85	54.80
Ignition Delay (ms)		4.562	4.528	4.119	4.298	4.083	3.703	3.707
Cold Filter Plugging Point (CFPP), (ºC)	D6371	-15.7	-15	-11	-15	-19	-6.7	-7
CHNS by combustion (wt%)	D5291							
C (wt%)		86.75	84.97	84.72	84.98	86.55	86.55	84.84
H (wt%)		12.66	12.57	12.65	12.66	13.14	13.14	13.15
N (wt%)		<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	< 0.15
S (wt%)		<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	< 0.40
Density by Digital Density Meter (API Gravity) at 60ºF	D4052							
API Gravity		34.98	33.64	34.06	33.64	37.95	39.04	36.95
Density (g/ml)		0.8491	0.8560	0.8538	0.8560	0.8342	0.8289	0.8392
Distillation	D86							
IBP (ºF)		331.3	344.7	344.3	341.6	333.3	345.4	349.5
T05 (ºF)		378.7	389.7	389.1	389.5	383.0	380.1	388.6
T10 (ºF)		397.8	412.0	410.9	412.2	406.0	399.2	411.1
T20 (ºF)		428.9	448.9	448.7	449.1	437.7	425.5	445.3
T30 (ºF)		456.3	484.7	484.0	483.6	466.3	450.5	476.1
T40 (ºF)		483.4	517.6	516.0	516.0	491.4	477.1	508.8
T50 (ºF)		509.0	546.3	543.0	545.0	511.7	502.3	538.5
T60 (ºF)		531.7	572.2	568.0	570.9	530.1	528.6	568.4
T70 (ºF)		554.9	594.9	589.8	593.4	548.2	556.3	594.1
T80 (ºF)		579.6	614.3	608.7	613.9	568.2	586.3	616.3
T90 (ºF)		610.7	631.6	627.1	632.5	597.6	622.9	636.6
T95 (ºF)		635.4	644.5	640.2	648.1	625.3	649.9	653.7
FBP (ºF)		659.7	661.8	658.0	664.2	652.8	675.3	674.2
Recovery (%)		98.0	98.3	98.3	98.1	98.4	99	99.4
Residue (%)		1.4	1.4	1.4	1.4	1.4	1.0	0.6
Loss (%)		0.6	0.3	0.3	0.5	0.2	0.0	0.0
Flash Point by Pensky-Martins Closed Cup (ºF)	D93	139	147	147	156	165	153	164
Lubricity by HFRR at 60ºC (microns)	D6079	315.5	180.5	186	172.5	386	415.0	156.5
Total Acid Number (mg KOH/g)	D664		<0.05	<0.05	0.07	<0.05		0.10
BTU Gross and Net by Bomb Calorimeter (Btu/lb)	D240							
BTU Gross (Btu/lb)		19,572	19,108	19,092	19,058	19,731	19,813	19,322
BTU Net (Btu/lb)		18,417	17,961	17,938	17,903	18,532	18,590	18,122
Viscosity by Capillary Viscometer (mm^2/s at 40ºC)	D445	2.654	2.809	2.896	2.898	2.543	2.536	2.907
Water by Karl Fischer Titration (ppm)	D6304	20	93	92	108	14	19	64

Table 2-3: Properties of the reference ULSD fuels, the biodiesel, and the renewable diesel blends (Continued)								
Property	**Method**	**Federal ULSD**	**Fed/ SME-20**	**Fed/ AFME-20**	**Fed/ WCO-20**	**Fed/ HVO-20**	**CARB ULSD**	**CARB/ WCO-20**
FAME in Diesel by FTIR-ATR-PLS (wt%)	EN14078							
FAME content (wt%)		<0.05	16.7	17.0	16.9	<0.05	<0.05	16.4
Range		A					A	B
Oxygen by Atomic Emission Detection w/ extraction prep	GC-AED-O w/ prep	0.03	3.14	3.13	2.98	0.02	0.02	2.47
Hydrocarbon Types by Fluorescent Indicator Absorption (FIA)	D1319							
Aromatics (vol%)		34.2	41.6	41.6	40.0	23.4	20.0	30.0
Olefins (vol%)		1.9	2.4	2.3	2.0	2.0	2.1	2.5
Saturates (vol%)		63.9	56.0	56.1	58.0	74.6	77.9	67.5
Aromatics by Supercritical Fluid Chromatography (SFC) (area% equiv to wt%)	D5186							
1 Ring Aromatics (area% equiv to wt%)		28.83	22.27	27.56	16.62	21.66	19.61	16.27
2 Ring Aromatics (area% equiv to wt%)		3.63	4.63	4.56	3.46	4.81	1.48	1.51
3+ Ring Aromatics (area% equiv to wt%)		0.14	0.44	0.29	0.29	0.43	0.00	0.00
Non-Aromatics (area% equiv to wt%)		67.40	57.07	53.77	69.44	70.10	78.91	68.89
Total Aromatics (area% equiv to wt%)		32.60	27.34	32.41	20.37	26.90	21.09	17.78
Oxidation Stability (hr)	EN15751	-	18.9	18.1	16.7	21.9	-	13.3
Metals by Inductively Coupled Plasma Mass Spectrometry (ppm)	ICP-MS							
V 51 (wtppm)	0.009							0.016
Cr 52 (wtppm)	0.010							0.008
Fe 56 (wtppm)	0.347							0.351
Co 59 (wtppm)	< 0.005							< 0.005
Ni 60 (wtppm)	< 0.005							< 0.005
Cu 63 (wtppm)	0.014							0.022
Zn 66 (wtppm)	0.151							0.226
As 75 (wtppm)	<0.005							<0.005
Se 78 (wtppm)	0.010							0.008
Ag 107 (wtppm)	< 0.005							< 0.005
Cd 111 (wtppm)	< 0.005							< 0.005
Sn 118 (wtppm)	0.165							0.221
Sb 121 (wtppm)	0.008							< 0.005
Ba 138 (wtppm)	< 0.005							0.005
Metals by Inductively Coupled Plasma Atomic Emission Spect (ppm)								
Al (wtppm)	< 0.6							< 0.6
Ba (wtppm)	< 1.1							< 1.1
Ca (wtppm)	< 0.7							< 0.7
Cd (wtppm)	< 0.6							< 0.6
Cr (wtppm)	< 0.9							< 0.9

Table 2-3: Properties of the reference ULSD fuels, the biodiesel, and the renewable diesel blends (Continued)								
Property	**Method**	**Federal ULSD**	**Fed/ SME-20**	**Fed/ AFME-20**	**Fed/ WCO-20**	**Fed/ HVO-20**	**CARB ULSD**	**CARB/ WCO-20**
Cu (wtppm)	< 1.1							< 1.1
Fe (wtppm)	< 1.1							< 1.1
Mg (wtppm)	< 0.7							< 0.7
Mn (wtppm)	< 0.7							< 0.7
Mo (wtppm)	< 0.9							< 0.9
Na (wtppm)	< 1.0							< 1.0
Ni (wtppm)	< 1.1							< 1.2
P (wtppm)	< 1.1							< 1.1
S (wtppm)	< 101							< 102
Si (wtppm)	< 0.6							< 0.6
Ti (wtppm)	< 0.9							< 0.9
V (wtppm)	< 1.1							< 1.1
Zn (wtppm)	< 0.7							< 0.7

Neat biodiesels and their blends with petroleum diesel undergo oxidation during prolonged storage periods. For this reason, the deterioration of the biodiesel blends (oxygenated blends) employed in this program was monitored after a period of approximately 12 months following the initial fuel quality check. Properties of interest included the oxidation stability of the blends, density, kinematic viscosity, acid number, and cetane number, as shown in Table 2.4. It is interesting to note that the oxidation stability for all biodiesel blends was found to be well above the ASTM minimum standard of 6 hours. However, all blends experienced a drop in oxidation stability in terms of their induction time over the 12 months when compared to the first samples from the 'freshly blended' blends, with the exception of CARB/WCO-20 blend. The effect of storage stability degradation was generally noticeable for some properties for most biodiesel blends, with the exception of CARB/WCO-20 blend. Increases in density, viscosity, and acid number were seen for the blends with the Federal ULSD, which is an indication of peroxides, acids, and polymeric compounds formation. The formation, to some extent, of peroxides and hydroperoxides of the methyl ester component in the blend may also positively affect the cetane number, since these species can act as cetane improvers.

Table 2-4: Key properties of biodiesel blends after a time period of 12 months

Property	Fed/SME-20		Fed/AFME-20		Fed/WCO-20		CARB/WCO-20	
	Fresh	12 mo.	Fresh	12 mo.	Fresh	12 mo.	Fresh	12 mo.
Derived Cetane Number by IQT	45.67	46.01	49.76	50.18	47.88	48.31	54.80	55.24
Ignition Delay (ms)	4.578	4.490	4.119	4.082	4.298	4.256	3.707	3.675
API gravity at 60°F	33.64	33.61	34.06	34.05	33.64	33.62	36.95	37.27
Density (g/ml)	0.8560	0.8562	0.8533	0.8539	0.8560	0.8561	0.8392	0.8376
Viscosity (mm^2/s)	2.809	2.814	2.896	2.902	2.898	3.033	2.907	2.728
Oxidation Stability (hr)	18.9	12.3	18.1	13.6	16.7	10.8	13.3	14.8
Acid number (mg KOH/g)	<0.05	0.05	<0.05	0.07	0.07	0.08	0.10	0.07

2.2 Test Vehicles

Eight test vehicles were chosen with the intent of representing the latest light-duty diesel technologies sold in the U.S. The test matrix included a mix of different manufacturers (both domestic and European) and passenger cars/trucks. The vehicles employed in this program, presented in a random order, were a 2012 model year (MY) Mercedes Benz ML 350, a 2012 MY Chevrolet Silverado 2500HD, 2012 MY Volkswagen Passat, a 2013 MY Ford F250 Super Duty, a 2013 MY Dodge Ram 2500, a 2013 MY BMW X5 35d, a 2014 MY Chevy Cruze, and a 2014 Jeep Grand Cherokee. The vehicles were all equipped with a DPF to reduce PM emissions, SCR technology to reduce NO_x emissions to comply with standards in California and other states, and a diesel oxidation catalyst (DOC) to control primarily CO and THC emissions and partly PM emissions. The recommended fuel for domestic vehicles was up to 20 vol% biodiesel (B20) according to the owner's manual, as opposed to the European vehicles where the recommended fuel was up to 5 vol% biodiesel (B5) in diesel fuel. The Mercedes Benz ML 350, Volkswagen Passat, and BMW X5 35d vehicles were provided in-kind by Mercedes-Benz, USA, Volkswagen of America, and BMW USA, respectively, while the remaining vehicles were purchased from private dealerships. For all eight vehicles, the aftertreatment system was assumed to be 'de-greened' as they had each accumulated more than 4,000 miles, and no reduction in catalytic activity due to aging was expected since all test vehicles had relatively low total mileage.

The 2012 Volkswagen Passat is a front-wheel drive vehicle that has a 2.0 liter, four-cylinder, in-line, turbocharged, direct injection, common-rail engine with a six-speed automatic transmission. The engine can deliver 140 horsepower at 4,000 rpm and 236 lb-ft torque at 1,750 rpm and has a compression ratio of 16.5:1. The vehicle was certified to Tier 2 Bin5/LEVII emissions standards and had 17,205 miles at the start of the test campaign.

The 2014 Chevrolet Cruze is a passenger car equipped with a 2.0 liter, four-cylinder, in-line, turbocharged, direct injection, common-rail engine. The engine can deliver 151 horsepower at 4000 rpm and 264 lb-ft at 2600 rpm and has a compression ratio of 16.5:1. The vehicle was certified to Tier 2 Bin5/LEVII emissions standards and had 6,433 miles at the start of the test campaign.

The 2013 BMW X5 35d is an all-wheel drive vehicle that has a 3.0 liter, six-cylinder, in-line, turbocharged, direct injection, common-rail engine. The engine can deliver 255 horsepower at 4000 rpm and 413 lb-ft at 1500-3000 rpm and has a compression ratio of 16.5:1. The vehicle was certified to Tier 2 Bin5/LEVII emissions standards and had 4,401 miles at the start of the test campaign.

The 2012 Mercedes Benz ML 350 is an all-wheel drive vehicle that has a 3.0 liter, six-cylinder turbocharged, direct injection, common-rail engine with a seven-speed automatic transmission. The engine can deliver 240 horsepower at 3,600 rpm and 455 lb-ft torque at 1,600-2,400 rpm, and has a compression ratio of 15.5:1. The vehicle was certified to Tier 2 Bin5/ULEVII emissions standards and had 8,228 miles at the start of the test campaign.

The 2014 Grand Jeep Cherokee is an all-wheel drive vehicle that has a 3.0 liter, six-cylinder, direct injection, common-rail engine. The engine can deliver 240 horsepower at 3600 rpm and 260 lb-ft at 4800 rpm and has a compression ratio of 15.5:1. The vehicle was certified to Tier 2 Bin5/LEVII emissions standards and had 4,262 miles at the start of the test campaign.

The 2013 Dodge Ram 2500 is a pickup truck fitted with a 6.7 liter, six-cylinder, in-line, turbocharged, direct injection, common-rail Cummins engine. The engine can deliver 370

horsepower at 2800 rpm and 800 lb-ft at 1700 rpm and has a compression ratio of 17.3:1. The vehicle was certified to Tier 2 Bin5/LEVII emissions standards and had 16,654 miles at the start of the test campaign.

The 2013 Ford F250 Super Duty pickup truck is a high volume sale product in the U.S. market. This vehicle has a 6.7 liter, eight-cylinder turbocharged, direct injection, common-rail engine. The engine can deliver 440 horsepower at 2800 rpm and 860 lb-ft torque at 1600 rpm and has a compression ratio of 16.2:1. The vehicle was certified to Tier 2 Bin5/LEVII emissions standards and had 10,017 miles at the start of the test campaign.

The 2012 Chevrolet Silverado 2500HD Duramax is a pickup truck that is widely available in the U.S. market. It is considered to be a light-duty diesel vehicle. This vehicle has rear-wheel drive and a 6.6-liter, eight-cylinder, turbocharged, direct injection, common-rail engine with a six-speed automatic transmission. The engine can deliver 397 horsepower at 3,000 rpm and 765 lb-ft torque at 1,600 rpm and has a compression ratio of 16.8:1. The vehicle was certified to Tier 2 Bin5/LEVII emissions standards and had 21,078 miles at the start of the test campaign.

Prior to the start of testing, the engine lubricating oil and oil filters on each vehicle were replaced at a local dealership according to manufacturer's recommendations. For the Mercedes Benz ML 350, fresh Mobil 1 SAE 5W-40, ESP Formula M low-ash motor oil was used. For the Chevrolet Silverado, fresh Mobil 1 SAE 5W-30 was used. For the Volkswagen Passat, aged lubricant oil in the engine was replaced with fresh full synthetic motor oil (Castrol EDGE, SAE 5W-30). For the BMW X5 35d, the fully synthetic BMW Longlife-04 SAE 5W-30 oil was used. For the Ford F250, Motorcraft SAE 10W-30 super duty diesel motor oil was used. For the Dodge Ram 2500, synthetic Mopar SAE 5W40 oil was used. For the Chevrolet Cruze, full synthetic Mobil 1 SAE 5W-30 motor oil was used. Finally, for the Grand Jeep Cherokee, synthetic blend Pennzoil SAE 5W-30 motor oil was used.

The main technical characteristics of the test vehicles are summarized in Table 2.5. Note that the vehicles are not listed in the table in the same order that they are shown in the figures such that the results are blind with respect to any of the specific test vehicles.

Table 2-5: Technical specification of the test vehicles used in this program

Engine	2.0L Turbo-diesel inline 4 cylinder	2.0L, 4 cylinder, inline, turbocharged	3.0L inline 6 cylinder	3.0L Turbo-diesel V6	3.0L, V6 cylinder	6.7L, 6 cylinder, inline, turbocharged	6.7L, V8 cylinder turbocharged	6.6L Turbo-diesel V8
Power	140 hp at 4,000 rpm	151 hp at 4000 rpm	255 hp at 4000 rpm	240 hp at 3,600 rpm	240 hp at 3600 rpm	370 hp at 2800 rpm	440 hp at 2800 rpm	397 hp at 3,000 rpm
Fuel injection	Common-rail direct fuel injection	Common-rail direct fuel injection	Common-rail direct fuel injection	Common-rail direct fuel injection	Common-rail direct fuel injection	Common-rail direct fuel injection	Common-rail direct fuel injection	Common-rail direct fuel injection
Torque	236 lb-ft at 1,750 rpm	264 lb-ft at 2600 rpm	413 lb-ft at 1500-3000 rpm	455 lb-ft at 1,600-2,400 rpm	260 lb-ft at 4800 rpm	800 lb-ft at 1700 rpm	860 lb-ft torque at 1600 rpm	765 lb-ft at 1,600 rpm
Compression ratio	16.5:1	16.5:1	16.5:1	15.5:1	15.5:1	17.3:1	16.2:1	16.8:1
Aftertreatment	DOC/DPF/SCR	DOC/DPF/SCR	DOC/DPF/SCR	DOC/DPF/SCR	DOC/DPF/SCR	DOC/DPF/SCR	DOC/DPF/SCR	DOC/DPF/SCR
Miles at start of testing	17,205	6,433	4,401	8,228	4,262	16,654	10,017	21,078
Emissions Standards	Tier 2 Bin5/LEVII	Tier 2 Bin5/LEVII	Tier 2 Bin5/LEVII	Tier 2 Bin5/ULEVII	Tier 2 Bin5/LEVII	Tier 2 Bin5/LEVII	Tier 2 Bin5/LEVII	Tier 2 Bin5/LEVII

2.3 Test Sequence, Randomization, and Fuel Conditioning

Each vehicle/fuel combination was tested at least twice using the Federal Test Procedure (FTP) test cycle, which is used for emission certification and fuel economy testing of light-duty vehicles in the U.S. Additional tests were conducted on some vehicles to evaluate emissions during operation that included particulate filter regeneration, as discussed in section 2.5. The FTP test cycle is shown in Figure 2.1.

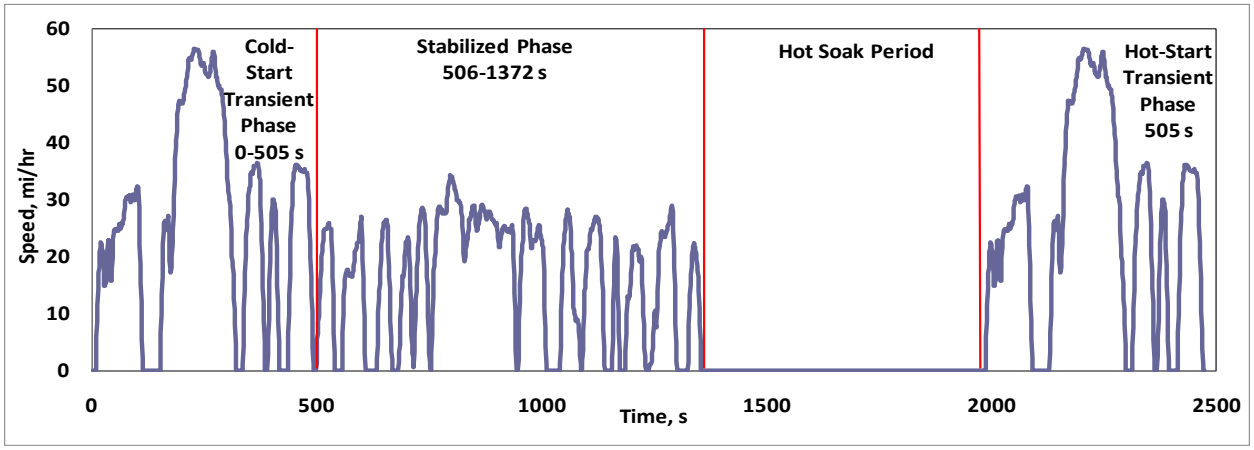


Figure 2-1: FTP Driving Cycle

The fuel testing sequence for each vehicle is provided in Table 2.6. The testing order of the fuels for each vehicle was randomized, subject to logistic considerations. The test vehicles are also presented in random order labelled as Vehicle #1 through Vehicle #8.

Table 2-6: Randomization Sequence for Each Vehicle

Vehicle #	Test Sequence
1	AEDFCBG
2	GACBEFD
3	GEFCBDA
4	CBEGFAD
5	DCEAFGB
6	GECBADF
7	FEDGABC
8	EGDABCF

Where: A= Fed ULSD; B=CARB ULSD; C=Fed/SME-20; D=Fed/AFME-20; E=Fed/WCO-20; F=Fed/HVO-20; and G=CARB/WCO-20

After completing the initial duplicate FTP tests on each vehicle/fuel combination, the data were evaluated to determine whether additional testing was required. A third test was performed if differences in FTP regulated emissions exceeded a predefined limit. This limit was defined using the same criteria as used in previous CRC studies, such as the E-60, E-67, E-83, and other older programs (Durbin et al., 2004; Painter and Rutherford 1992). Specifically, a third test was performed if the difference in the measurements exceeded the following: THC 33%, NO_x 29%, CO 70%, provided the absolute difference in the measurements was greater than 5 mg/mi. The emissions measurements for the third test also included the carbonyl compounds, PM mass, EC/OC fractions, real-time ammonia, PAHs/nitro-PAHs, and particle number emissions and particle size distributions.

Before each test on a specific vehicle, the engine oil was changed, as discussed above. Following the oil change, the vehicle was conditioned on the oil for a period approximately equivalent to two US06 cycles, followed by an LA4 and a US06 cycle sequence repeated twice (i.e., a total of 4 US06 cycles and 2 LA4s). The preconditioning for the oil was done with either the fuel in the tank or with the first fuel in the fuel randomization sequence for each vehicle. More specifically, the oil preconditioning procedure for Vehicle #1, Vehicle #2, Vehicle #3, Vehicle #5, Vehicle #6, and Vehicle #7 was done with the retail fuel in the tank (regular CARB diesel), while preconditioning for Vehicle #4 and Vehicle #8, the oil preconditioning was done with Fed/SME-20 and Fed/WCO-20, respectively.

Before each test on a specific vehicle/fuel combination, the vehicle was preconditioned with a procedure that included a fuel drain and fill (40%), followed by a catalyst sulfur purge cycle, four coast downs (70-30 mph), two additional drain and fills, and preconditioning driving over an LA4 on the dynamometer. In cases where back-to-back tests were conducted on the same vehicle/fuel combination, no additional preconditioning was performed, unless the time between tests exceeded the FTP time limit of 36 hours for soak time, such as for breaks in testing due to weekends. In these cases, the vehicle was operated over an additional FTP cycle prior to the official FTP test. Vehicles under active test were stored indoors in a temperature-controlled soak area adjacent to the test cell. Figure 2.2 summarizes the fuel and oil conditioning procedure in a flow chart. This sequence was used for all vehicles and fuels, including passenger cars and light-duty trucks.

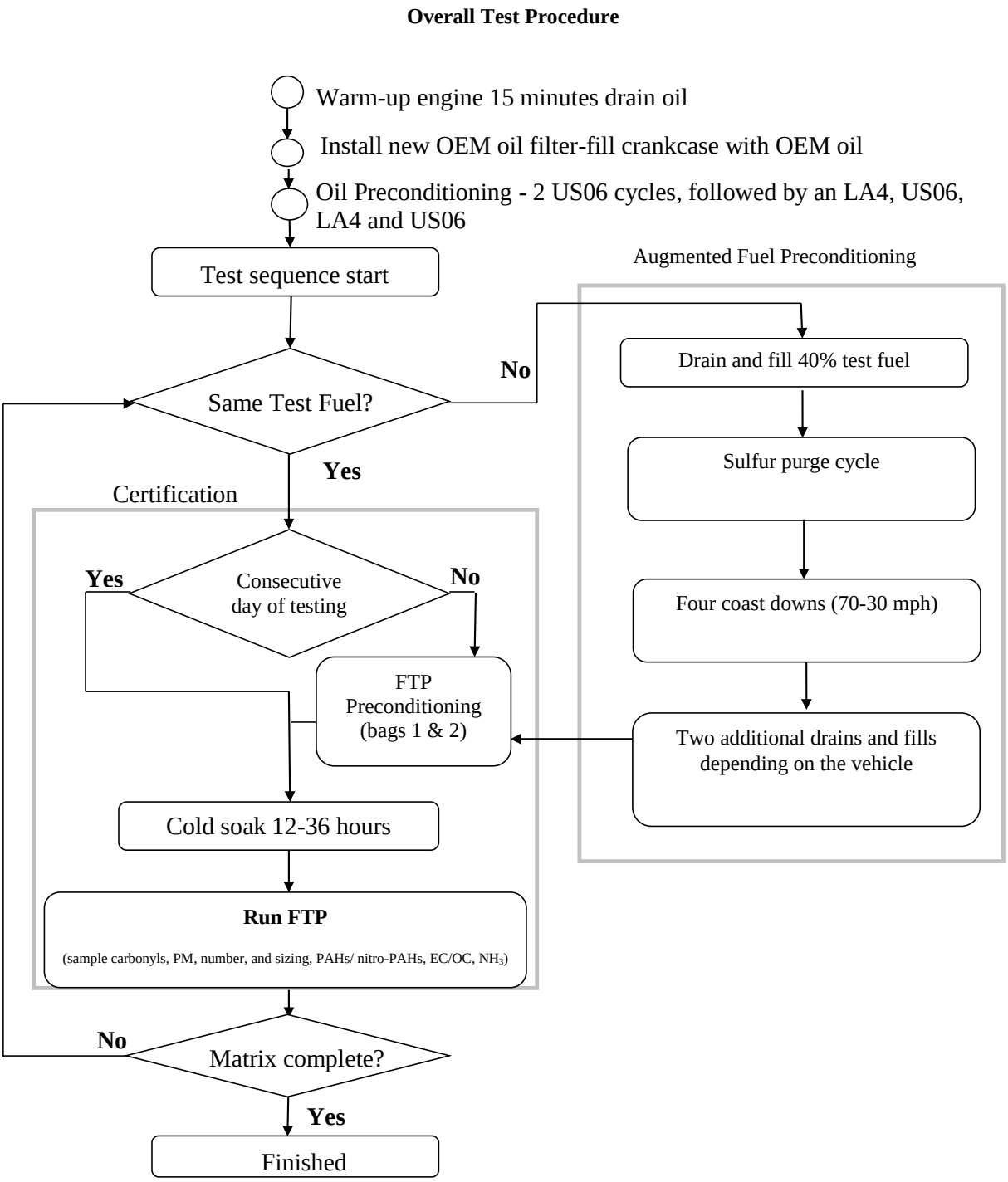


Figure 2-2: Test sequence for fuel change procedure and oil conditioning

2.4 Emissions Testing

Vehicle emissions measurements were conducted in CE-CERT's Vehicle Emissions Research Laboratory (VERL). The centerpiece of the VERL is a 48-inch Burke E. Porter single-roll electric chassis dynamometer, capable of testing vehicles weighing up to 12,000 lbs. A Pierburg Positive Displacement Pump-Constant Volume Sampling (PDP-CVS) system was used to obtain certification-quality emissions measurements.

For each FTP test, standard bag and modal tailpipe measurements were made for THC, non-methane hydrocarbons (NMHC), methane (CH_4), NO_x, CO, CO_2, and fuel economy. The VERL configuration utilizes a Pierburg/AVL AMA-4000 emissions bench for the measurement of both the bag emissions and the second-by-second post-catalyst measurements. The Pierburg AMA-4000 includes a flame ionization detector (FID) for THC and NMHC emissions, a chemiluminescence analyzer for NO_x emissions and a non-dispersive infrared (NDIR) analyzer for CO and CO_2. Fuel economy was determined using CO_2 and the other emissions using the carbon balance method, as discussed below. The detection limits of the AMA-4000 are 0.2 ppm, 0.05 ppm, and 0.5 ppm, respectively, for THC, NO_x, and CO. All gaseous emissions were determined according to EPA protocols for light-duty emission testing as given in the Code of Federal Regulations, Title 40, Part 86, and within the accuracy limitations established therein.

PM Mass and Number Measurements

PM measurements were made on both a mass and number basis. Because of the very low levels of PM emissions expected from the modern technology, DPF-equipped diesel vehicles to be tested, PM mass samples were collected cumulatively over the entire FTP cycle, with one sample collected for each test. PM mass samples were collected at a filter face velocity of 100 cm/s, consistent with Code of Federal Regulations, Title 40, Part 1065, although other provisions of Part 1065, such as control of the temperature at the filter face to 47±5 °C and meeting requirements on residence time, were not incorporated into the PM sampling protocol. Tunnel blank samples were collected throughout the program for a total of 15 background samples for the PM sampling. Total PM mass determinations were collected using 47 mm Teflon® filters and measured with a 1065-compliant microbalance in a temperature- and humidity-controlled clean chamber.

Total particle number (PN) was also measured using a TSI 3776 ultrafine-Condensation Particle Counter (CPC). This is a butanol-based CPC able to count particles down to 2.5 nm. This instrument can sample about 300,000 particles per second, making the ultrafine CPC ideal for an accurate total PN measurement.

Real-time particle size distributions were also obtained using an Engine Exhaust Particle Sizer (EEPS) spectrometer. The EEPS was used to obtain real-time, second-by-second size distributions from 5.6 to 560 nm. Particles were sampled at a flow rate of 10 lpm, which is sufficiently high to minimize diffusional losses. They were then charged with a corona charger and sized based on their electrical mobility in an electrical field. Concentrations were determined through the use of multiple electrometers.

Since regeneration of the DPF produced exhaust particle concentrations that were higher than the maximum limit of 300,000 particles per second for the CPCs, a portable secondary dilution system was implemented to reduce the concentration of particles entering the ultrafine CPC for this element of the test program (discussed below). This system took diluted exhaust from the CVS and further diluted it with clean compressed air in a well-mixed chamber. Three of these systems were employed during the regeneration testing. The SMPS utilized one of the secondary dilution systems with a dilution ratio of 12:1. The EEPS and ultrafine CPC used two secondary dilution systems in series with a total dilution ratio of 600:1.

Elemental Carbon and Organic Carbon Analysis

Elemental and organic carbon samples (EC/OC) were collected in parallel on pre-cleaned QAT Tissuquartz quartz-fiber filters (Pall-Gelman, Ann Arbor, MI, USA). Quartz fiber filters were

pre-cleaned to remove carbonaceous contaminants by firing for 4 hours at 600 ºC. These filters were stored in dark sealed petri dishes at 0 ºC until use.

A Thermal/Optical Carbon Aerosol Analyzer (Sunset Laboratory, Forest Grove, OR) operating on the NIOSH (National Institute of Occupational Safety and Health) Method 5040 was used to analyze OC and EC. This analytical method has two stages. In the first stage, organic and carbonate carbon (if present) are volatilized from the sample in a pure helium atmosphere as the temperature is stepped to about 820 ºC. Evolved carbon is catalytically oxidized to CO_2 in a bed of granular MnO_2, reduced to CH_4 in a nickel-firebrick methanator and quantified as CH_4 by a flame ionization detector (FID). During the second stage of the analysis, measurements to correct for the pyrolysis of OC and EC measurements are made. The oven temperature is lowered to 60ºC, a 1:9 oxygen–helium mix is introduced and the oven temperature is then raised to about 860ºC. As oxygen enters the oven, pyrolytically generated EC from OC is oxidized and a concurrent increase in filter transmittance occurs. Correction for the char contribution to EC is made by measuring the amount of char oxidation required to return the filter to its initial transmittance value. More details on the analysis can be found elsewhere (Birch and Cary, 1996). The detection limit is 0.2 mg C.

Carbonyl Compounds Sampling and Analysis

Samples for carbonyl analysis were collected through a heated line onto 2,4-dinitrophenylhydrazine (DNPH) coated silica cartridges (Waters Corp., Milford, MA). Sampled cartridges were extracted using 5 mL of acetonitrile and injected into an Agilent 1200 series high performance liquid chromatograph (HPLC) equipped with a variable wavelength detector. The column used was a 5 µm Deltabond AK resolution (200cm x 4.6mm ID). The HPLC sample injection and operating conditions were set up according to the specifications of the SAE 930142HP protocol (Siegl et al., 1993).

Ammonia Measurements

Measurements of ammonia (NH_3) were also obtained on a real-time basis using a tunable diode laser near infrared absorption spectrometer (TDL). The TDL system was used because it provided significant advantages for the measurement of exhaust NH_3 in sensitivity, response time, and the ability to measure in situ in raw exhaust.

PAH and nitro-PAH Sampling and Analysis

PAH and nitro-PAH samples were collected on Teflon®-impregnated glass fiber (TIGF) filters (100 mm). Prior to the sample collection, TIGF filters were cleaned by sonication for 10 minutes in dichloromethane (CH_2Cl_2) twice, with the solvent replaced and drained, and sonicated for 10 minutes in methanol twice with the solvent replaced. Filters are then dried in a vacuum oven at 50°C for minimum of 24 hours, placed in foil packages that have been fired at 500 °C for 4 hours, placed in Uline metallic ZipTop static shielding bags, and stored at room temperature. Amberlite XAD-4 polyaromatic absorbent resin (Aldrich Chemical Company, Inc.) was washed with Liquinox soap and rinsed with hot water, followed with deionized (DI) water and technical grade methanol (3-4 times). The XAD-4 was then extracted using a Dionex Accelerated Solvent Extractor (Dionex Corporation, Sunnyvale, CA) for 15 min/cell with dichloromethane (CH_2Cl_2) at 1500 psi and 80°C, followed by acetone. It was then dried in a vacuum oven at 50°C. Cleaned XAD-4 was packed into a glass cartridge and placed in Uline ZipTop metallic static-shielding bags and stored in clean room at room temperature. Sample preparation was done in part at the Desert Research Institute (DRI) and in part in CE-CERT's internal chemical laboratories.

Cartridges prepared at DRI were packed in plastic tubes with field data sheets with the same unique PMI number and shipped in coolers on blue ice priority mail overnight to CE-CERT.

The SVOC collected on each filter-XAD sampling train were extracted separately with high-purity, HPLC-grade dichloromethane (DCM) followed by acetone by accelerated solvent extraction (ASE). The ASE method pressurized and heated the media for 15 min/cell at 1500 psi and 80°C. The following deuterated internal standards were added to the media (XAD and filters) prior to extraction: naphthalene-d_8, acenaphthylene-d_8, phenanthrene-d_{10}, anthracene-d_{10}, chrysene-d_{12}, pyrene-d_{10}, benz[a]anthracene-d_{12}, benzo[a]pyrene-d_{12}, benzo[e]pyrene-d_{12}, benzo[k]fluoranthene-d-$_{12,}$ benzo[g,h,i]perylene-d_{12}, coronene-d_{12}, 1-nitronaphthalene-$d_{7,}$ 2-nitrobiphenyl-$d_{9,}$ 1-nitrofluorene-$d_{9,}$ 9-nitroanthracene-$d_{9,}$ 3-nitrofluoranthene-$d_{9,}$ 1-nitropyrene-$d_{9,}$ 9-nitrochrysene-$d_{11,}$ 6-nitrobenzo[a]pyrene-$d_{11.}$ Extracts were concentrated to ~1mL by rotary evaporation at 35-45°C under gentle vacuum, and filtered through a 0.2 µm PTFE disposable filter (Whatman Pura disc TM 25TF). Filtrate was collected in a 4 mL amber glass vial for a total volume of ~4 mL (including flask rinse with solvent). Approximately 500 µl of hexane was added at this time, and the extracts were reduced in volume under a gentle stream of ultra high purity (UHP) nitrogen (with a Chrompack CP-Gas-Clean moisture filter) to ~250 µL.

The sample extracts were extremely complex and required extensive clean-up prior to PAH and nitro-PAH analysis to remove interferences, which reduce peak resolution and increase baseline noise. Isolation of the PAH and nitro-PAH-rich fraction was achieved with the use of a solid-phase extraction (SPE) aminopropyl Sep-Pak cartridge (Waters, Milford, MA). Sep-Pak cartridges (3 mL, 500 mg) were first pre-conditioned with 3 mL DCM followed by 3 mL hexane. The sample extract was then transferred onto the cartridge and eluted with 5 mL 2% DCM in hexane, followed by 5 mL of 20% DCM in hexane. Approximately 100 µl of toluene was added at this time, and the extracts were reduced in volume under a gentle stream of UHP nitrogen (with a Chrompack CP-Gas-Clean moisture filter) to ~100 µL. The final extract volume was adjusted to 100 µL with toluene and analyzed for non-polar analytes without further alteration.

The analysis of the PAH and nitro-PAH extracts were both performed at the Desert Research Institute, Reno, NV. The XAD cartridge extracts were analyzed separately by electron impact (EI) GC/MS for PAHs using a Varian 4000 GC/MS system equipped with a CP-8400 autosampler. A 1 µL injection onto a 30-m 5% phenylmethylsilicone fused-silica capillary column (DB-5MS+DG, J&W Scientific, Folsom CA) was performed. Compounds and corresponding deuterated internal standards were quantified by selective ion monitoring (SIM). Additional analyses were performed for filter PAH and nitro-PAH on a Scion 456 GC interfaced with a Scion TQ triple quadrupole MS/MS and equipped with CP-8400 autosampler, due to the superior sensitivity of this instrument. The PAH method utilized the same capillary column mentioned previously, while the nitro-PAH method required a 30-m DB-17MS column (J&W Scientific, Folsom CA). Negative ion chemical ionization (NICI) with methane as a reagent gas was utilized for nitro-PAH analysis to enhance detection sensitivity.

A 6-level calibration was performed for each compound of interest, and a mid-level check standard was run at least once every ten samples. If the relative accuracy of measurement (defined as a percentage difference from the standard value) was greater than 20%, then the instrument underwent routine injector/column/detector cleanup (or replacement) followed by recalibration. Nitro-PAH analysis is particularly sensitive to column age, due to the chemical affinity of target compounds to active sites.

2.5 Regeneration Emissions Testing Protocol

A protocol was developed and implemented to evaluate emissions during a period of vehicle operation that included regeneration of the particulate filter. This protocol was included in the emissions testing performed on Vehicle #1 and Vehicle #3 during their respective operation on Federal ULSD and Fed/SME-20. The regeneration testing was incorporated into the test matrix at the same point where these two fuels were otherwise being tested. Within the test matrix, the regeneration testing was done immediately after the main test sequence of either two or three tests was done on the fuel being evaluated. Prior to the first FTP on the Federal ULSD and Fed/SME-20 fuels, the vehicle was forced to regenerate to establish a baseline and remove potential impacts and carryover effects from the DPF from other fuels tested on the particular vehicle. The regeneration testing was conducted following the regular two or three FTPs that were being conducted as part of the test matrix.

For Vehicle 1, the regeneration event was triggered externally in the laboratory. After the vehicle was driven on-road to build up soot, technical personnel from the manufacturer instrumented the vehicle and manually triggered a DPF regeneration mode over the HWFET cycle. For vehicle 3, the manufacturer programmed the vehicle's ECM to regenerate every 170 miles.

The regeneration testing protocol included driving each vehicle on-road on a route designed to simulate the LA4 portion of the FTP cycle in terms of typical speeds as well as number of stops, for approximately 160 miles (20 LA4s) to build up soot in the DPF. Regulated emissions, PM mass, particle number emissions and particle size distributions, carbonyls, PAHs/nitro-PAHs, EC/OC, and NH_3 emissions were measured during a regeneration event for each vehicle/fuel combination over the EPA Highway Fuel Economy Cycle (HWFET). The HWFET (Figure 2.3) is a chassis dynamometer driving schedule, developed by the U.S. EPA for the determination of highway fuel economy of light-duty vehicles. The duration of the cycle is 765 seconds, the total distance is 10.26 miles, and the average speed is 48.3 miles/hour.

A double HWFET was conducted for each vehicle/fuel combination to provide ample time for the regeneration to be completed. The same protocol was repeated for each test fuel to collect a second set of samples of every emission component. To provide a baseline for comparison, a baseline double HWFET emissions test was conducted after the FTP testing was completed on the Federal fuel, but prior to any of the on-road HWFET conditioning. This baseline double HWFET was only conducted on the Federal ULSD.

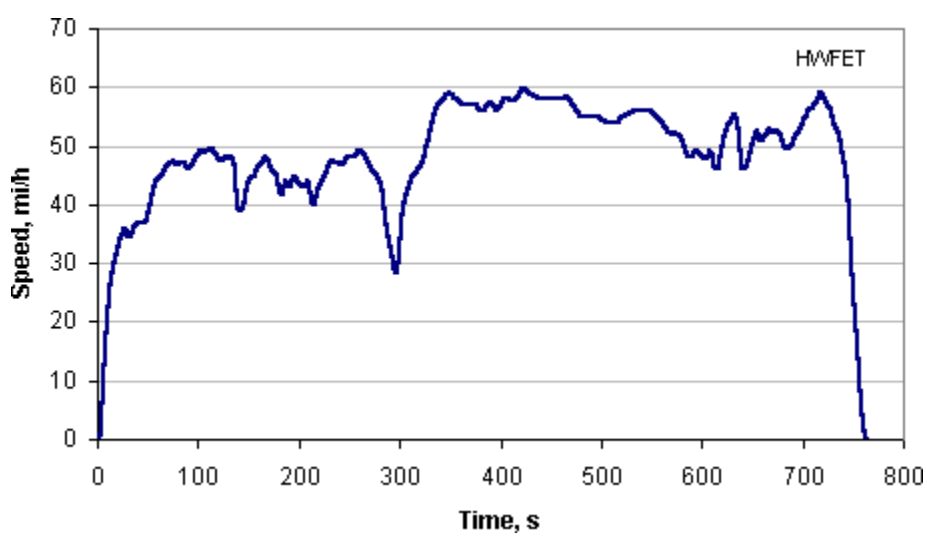


Figure 2-3: U.S. EPA HWFET Cycle

2.6 Statistical Analysis

Statistical analyses for selected emission pollutants were run using the Mixed procedure in PC/SAS from SAS Institute, Inc. Mixed models include both fixed and random factors. The fuel type was treated in the model as a fixed factor, that is, the levels of this factor were the specific fuel types of interest. Vehicles were included as a random factor. Although the vehicles were recruited for testing based on criteria for specific vehicle manufacturers or aftertreatment technologies, the vehicles were still selected at random from the larger population of vehicles of that specific manufacturer/technology within the in-use fleet. This was done to allow extrapolation of the results of the fuel effects onto a larger population of vehicle types, not just those that were used in the experiment. The mixed models were performed for each pollutant to determine the statistical significance of any fuels effects. The fixed effect included in the model was the fuel type and the random effect was vehicle.

The normality of residuals was checked in the models for all regulated and toxic emissions to determine if a transformation was necessary. Analyses using the logarithmic transform of the data in similar previous studies have shown that the emissions standard deviation is relatively constant as a percentage of the emission level. For example, vehicles with higher emission levels will tend to have a higher variability on an absolute basis than those with lower emissions levels. Examination of the current data revealed that this relationship between the emissions level and variability held true even for the very low-emitting vehicles. All the emissions were analyzed on the natural logarithm scale. Fuel economy was analyzed in the inverse scale (i.e., gallons/mile). For emissions components that included zeros for individual bags or weighted emissions, a small constant was added prior to taking the logarithm to allow the analyses to be done in the logarithm scale. Any added constants were selected to be as small as possible, and in all cases did not exceed the background levels.

For pollutants where the Mixed model showed a statistically significant for a particular driving cycle phase, pairwise comparisons were made using a least significant difference test to determine the fuel pairs for which statistically significant differences were found. Statistical analysis results were considered to be statistically significant for $p \leq 0.05$, although there are also cases noted where $0.05 < p \leq 0.1$ as marginally statistically significant in the text. The results from the ln or inverse models were “back transformed” to provide least square means for all pollutants on each fuel. This provided an arithmetic measure to evaluate the magnitude of any statistically significant effects. Any constants added to facilitate the analysis in logarithm scale were subsequently subtracted from the least square means after the back transformation to the arithmetic scale was made. This analysis only treats individual pairwise comparisons. Basis probability theory clearly shows that the likelihood of multiple comparisons being significant simultaneously will be at a lower level of probability. This analysis was not conducted in a way that validates multiple, simultaneous, comparisons.

The regeneration testing results were not included in the main statistical analyses using the Mixed model, since the regeneration testing was done ancillary to the main test matrix. For the regeneration emissions testing, results were separately analyzed using a simple equal variance, two-tailed *t*-test to evaluate the statistical significance between the two fuels employed in the regeneration testing.

3. Emissions Testing Results

This section presents and discusses figures which show the weighted FTP regulated and unregulated emission results for the eight diesel vehicles tested. The results for each test vehicle/fuel combination represent the average of all test runs done on that particular combination. The error bars represent one standard deviation on the average values for the individual vehicles. It should be noted that the error bars for some pollutants were below zero for some vehicle/fuel combinations, which suggests that the measurements were close to the CVS tunnel background measurement levels. Detailed results for the statistical analyses and the results for individual vehicles are provided in Appendix A, Appendix B, Appendix C, and Appendix D, respectively.

3.1 THC, NMHC, and CH_4 Emissions

The weighted FTP THC, NMHC, and CH_4 emissions results are presented in Figures 3.1, 3.2, and 3.3, respectively. Emissions of THC were generally found in very low concentrations for all vehicle/fuel combinations ranging from 0.012 to 0.083 g/mile, as shown in Figure 3.1. Overall, THC emissions showed some trends of lower emissions with the use of some biodiesel blends and CARB ULSD compared to Federal ULSD. The weighted THC emissions showed statistically significant differences between fuels, with CARB ULSD and CARB/WCO-20 blend showing decreases of 18% and 16%, respectively, compared to Federal ULSD. Statistically significant increases in weighted THC emissions of 19% and 17%, respectively, were also found for Fed/SME-20 and Fed/WCO-20 blends compared to CARB ULSD.

The cold-start phase of the FTP dominated the THC emissions as a result of the cold engine and the DOC being below its light-off temperature. For most vehicles, hot-running and hot-start THC emissions were found to be substantially lower than cold-start THC emissions, as shown in Table 3.1. Hot-start THC emissions for Vehicle #7 and Vehicle #8 were generally higher than hot-running THC emissions, whereas the light-duty truck Vehicle #6 showed comparable cold-start THC emissions to the passenger car Vehicle #3 and approximately three times lower cold-start THC emissions than the passenger car Vehicle #7. For Vehicle #7, it is assumed that this phenomenon in terms of less efficient THC oxidation in the aftertreatment systems is related to the lower catalyst size or different catalyst type. Statistically significant differences between fuels in THC emissions were also seen during the cold-start phase of the FTP cycle. Similar to weighted THC emissions, CARB ULSD showed a statistically significant decrease of 20% relative to Federal ULSD, while CARB/WCO-20 showed a marginally statistically significant decrease of 14% relative to Federal ULSD. Statistically significant increases in THC emissions on the order of 31% and 24%, respectively, were seen for Fed/SME-20 and Fed/WCO-20 blends compared to CARB ULSD. The blends of Fed/AFME-20, Fed/WCO-20, and CARB/WCO-20 also showed statistically significant reductions in THC emissions of 17%, 15%, and 18%, respectively, compared to Fed/SME-20 blend. Statistically significant effects in THC emissions were also observed during the hot-running phase of the FTP, but not for the hot-start phase. For the hot-running phase, CARB ULSD showed marginally statistically significant lower THC emissions (18%) and CARB/WCO-20 showed statistically significant lower THC emissions (23%) both compared to Federal ULSD. Statistically significant lower THC emissions (20%) were also seen for CARB/WCO-20 compared to Fed/SME-20.

Table 3-1: Cold-start, hot-running, and hot-start THC emissions, expressed in g/mile, for all vehicle/fuel combinations over the FTP cycle

	Vehicle #1			**Vehicle #2**		
	Cold-start	Hot-running	Hot-start	Cold-start	Hot-running	Hot-start
Federal ULSD	0.099	0.017	0.008	0.166	0.032	0.035
CARB ULSD	0.074	0.011	0.005	0.133	0.037	0.030
Fed/SME-20	0.109	0.013	0.006	0.175	0.037	0.031
Fed/AFME-20	0.084	0.013	0.007	0.149	0.042	0.038
Fed/WCO-20	0.099	0.015	0.005	0.146	0.031	0.032
Fed/HVO-20	0.087	0.012	0.007	0.139	0.039	0.037
CARB/WCO-20	0.082	0.010	0.007	0.147	0.039	0.038
	Vehicle #3			**Vehicle #4**		
	Cold-start	Hot-running	Hot-start	Cold-start	Hot-running	Hot-start
Federal ULSD	0.049	0.012	0.008	0.126	0.036	0.022
CARB ULSD	0.038	0.011	0.009	0.106	0.029	0.015
Fed/SME-20	0.062	0.011	0.007	0.138	0.029	0.018
Fed/AFME-20	0.044	0.011	0.008	0.116	0.024	0.016
Fed/WCO-20	0.069	0.011	0.007	0.121	0.030	0.017
Fed/HVO-20	0.047	0.012	0.010	0.128	0.026	0.016
CARB/WCO-20	0.046	0.011	0.009	0.108	0.021	0.013
	Vehicle #5			**Vehicle #6**		
	Cold-start	Hot-running	Hot-start	Cold-start	Hot-running	Hot-start
Federal ULSD	0.320	0.024	0.018	0.037	0.015	0.010
CARB ULSD	0.217	0.013	0.012	0.024	0.013	0.008
Fed/SME-20	0.244	0.022	0.017	0.034	0.010	0.006
Fed/AFME-20	0.303	0.023	0.017	0.024	0.011	0.007
Fed/WCO-20	0.222	0.019	0.016	0.047	0.020	0.013
Fed/HVO-20	0.264	0.015	0.012	0.024	0.012	0.007
CARB/WCO-20	0.274	0.015	0.014	0.024	0.011	0.006
	Vehicle #7			**Vehicle #8**		
	Cold-start	Hot-running	Hot-start	Cold-start	Hot-running	Hot-start
Federal ULSD	0.134	0.011	0.023	0.137	0.012	0.090
CARB ULSD	0.104	0.008	0.023	0.162	0.012	0.082
Fed/SME-20	0.160	0.016	0.030	0.143	0.012	0.069
Fed/AFME-20	0.107	0.008	0.022	0.120	0.012	0.073
Fed/WCO-20	0.114	0.008	0.021	0.130	0.011	0.076
Fed/HVO-20	0.103	0.008	0.025	0.162	0.013	0.098
CARB/WCO-20	0.098	0.007	0.024	0.164	0.013	0.092

The CARB ULSD showed lower THC emissions relative to Federal ULSD for seven out of the eight vehicles. The CARB ULSD's lower aromatics and higher cetane number relative to the Federal ULSD were probably the main contributors to the lower THC emissions. Most studies of biodiesel in uncontrolled engines have shown reduced THC emissions relative to petroleum diesel. The higher oxygen concentration of biodiesel is one of the main factors contributing to lower THC emissions, although the absence of aromatic content as well as the advanced injection and combustion timing also promote more complete combustion. Moreover, the higher cetane number of biodiesel contributes to the reduction of the ignition delay, where a large

amount of HC is formed (Lapuerta et al., 2008a; Giakoumis et al., 2012). Overall, studies conducted on modern technology vehicles where the cold-start phase dominates THC emissions show that the biodiesel benefit for THC has somewhat faced. Many authors in related studies have reported either insignificant changes or even increases in THC emissions for biodiesel relative to ULSD (Martini et al., 2007; Bannister et al., 2010; Fontaras et al., 2010b; Rose et al., 2010; Bakeas et al., 2011b). These results also showed some consistent increases in THC emissions for the unsaturated Fed/SME-20 compared to the other biodiesel blends. This phenomenon could be ascribed to the lower cetane number of soy-based biodiesel compared to the other biodiesel fuels used in this study. The results reported here also showed consistent cold-start and weighted THC increases for the biodiesel blends compared to CARB ULSD. It is possible that the lower volatility of biodiesel compared to petroleum diesel combined with biodiesel's lower heating value may lead to higher levels of HC with high molecular weights which are difficult to vaporize and burn. This lower volatility may also cause higher fuel consumption that could form localized regions with higher fuel-to-air ratios resulting in increased THC emissions.

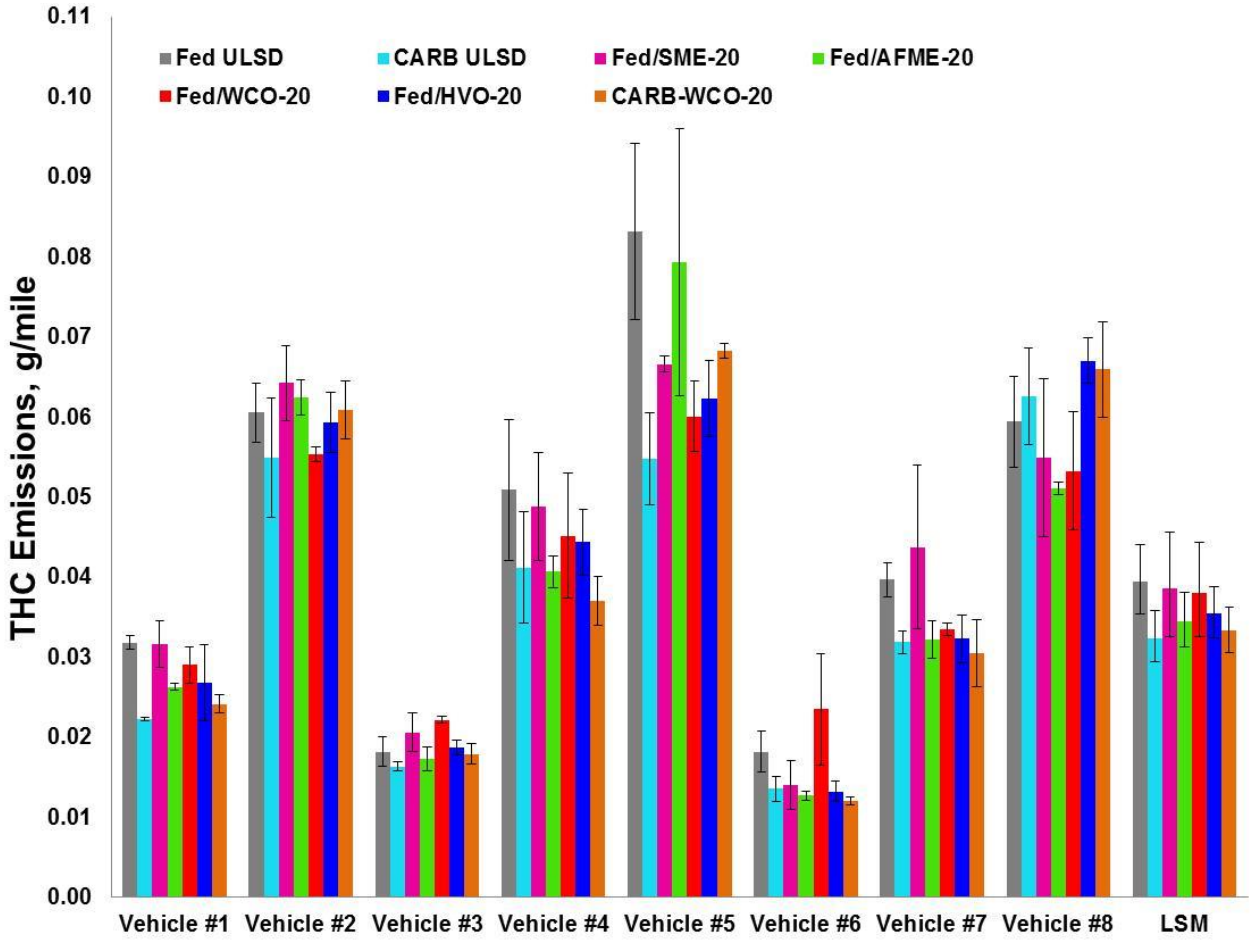


Figure 3-1: Weighted THC emissions over the FTP

Emissions of NMHC were found at very low concentrations for all vehicle/fuel combinations, as shown in Figure 3.2. For the weighted NMHC emissions, CARB ULSD and Fed/HVO-20 showed statistically significant reductions of 28% and 24%, respectively, compared to Federal ULSD. Compared to CARB ULSD, the blends of Fed/SME-20 and Fed/WCO-20 also showed statistically significant increases in NMHC emissions of 48% and 49%, respectively. Similar to THC emissions, the blends of Fed/AFME-20, Fed/WCO-20, and CARB/WCO-20 showed statistically significant reductions compared to Fed/SME-20. In addition, Fed/WCO-20 showed a statistically significant increase in weighted NMHC emissions of 32% relative to Fed/AFME-20,

whereas Fed/HVO-20 and CARB/WCO-20 showed statistically significant reductions of 29% and 26%, respectively, relative to Fed/WCO-20 blend.

For the cold-start phase of the FTP, CARB ULSD, Fed/HVO-20 and CARB/WCO-20 exhibited statistically significant reductions in NMHC emissions of 29%, 18% and 18%, respectively, compared to Federal ULSD. The blends of Fed/SME-20 and Fed/WCO-20 showed statistically significant increases in NMHC emissions of 60% and 50%, respectively, and the Fed/AFME-20 a marginally statistically significant 20% increase compared to CARB ULSD. Statistically significant reductions of 25%, 28%, and 29% were also seen for Fed/AFME-20, Fed/HVO-20, and CARB/WCO-20, respectively, compared to Fed/SME-20. Similar to weighted NMHC emissions, Fed/WCO-20 showed a statistically significant increase of 24% compared to Fed/AFME-20, whereas Fed/HVO-20 and CARB/WCO-20 showed statistically significant reductions of 23% and 24%, respectively, relative to Fed/WCO-20 blend. For the hot-running phase, there were no statistically significant effects between the fuels, while for the hot-start phase Fed/HVO-20 showed a statistically significant reduction in NMHC emissions of 47% compared to both Federal ULSD and Fed/WCO-20.

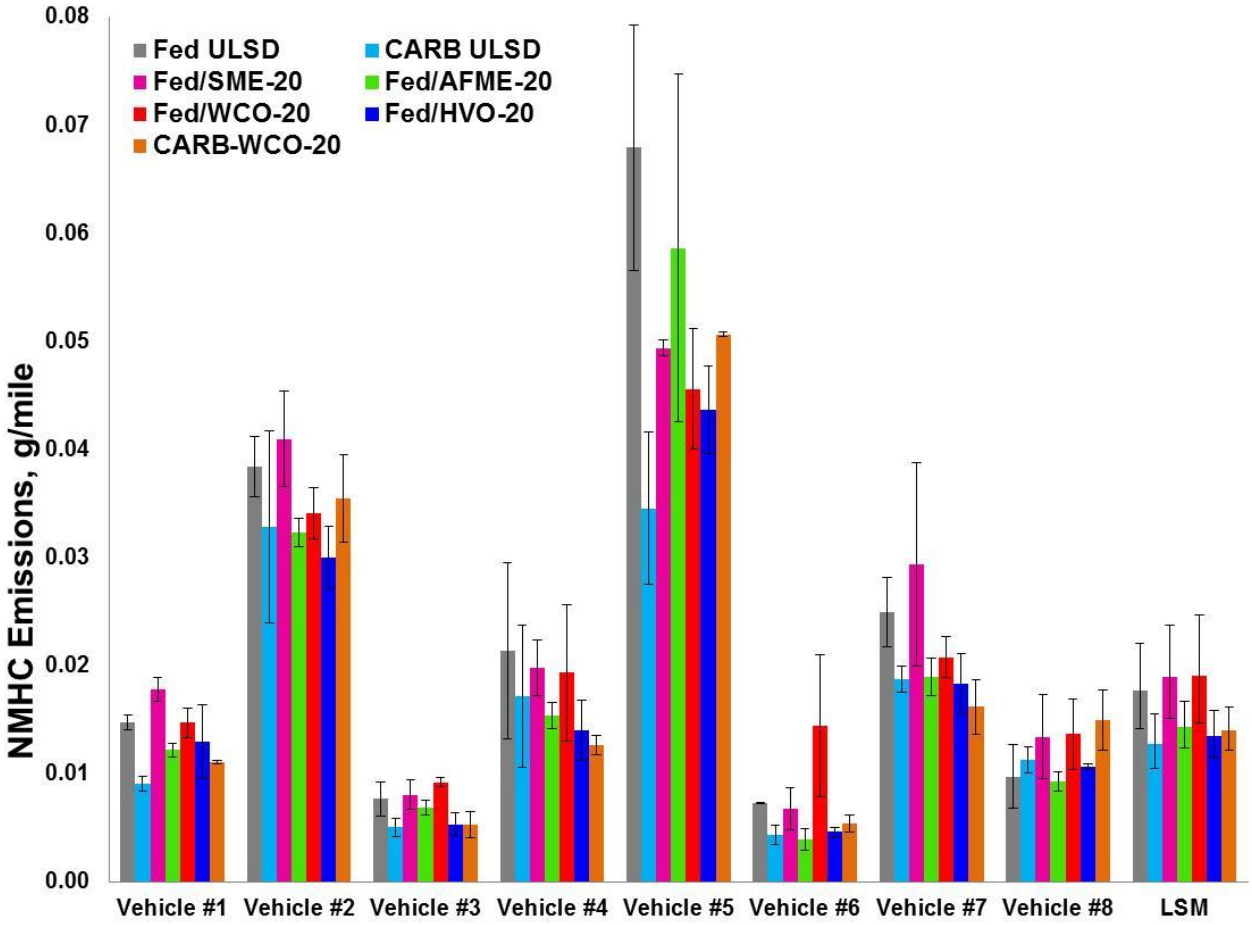


Figure 3-2: Weighted NMHC emissions over the FTP

Methane (CH_4) emissions are presented in Figure 3.3. While CH_4 is not toxic and not relevant to ozone-forming potential, CH_4 emissions are a strong greenhouse gas that must be accounted for. A fairly large body of data reporting CH_4 emissions from gasoline-fueled light-duty vehicles exists. However, there is limited information concerning the magnitude of CH_4 emissions from modern technology light-duty diesel vehicles operated with alternative fuel formulations and their contribution to the global and regional CH_4 inventory. For this program, CH_4 emissions were at very low levels for most vehicle/fuel combinations over the FTP cycle, ranging from 0.008 to 0.065 g/mile. For the weighted CH_4 emissions, Fed/HVO-20 showed a statistically

significant increase of 15% compared to Fed/WCO-20, while the test fuels had the same effect on CH_4 emissions during the cold-start phase. For the hot-running phase, CARB/WCO-20 showed a marginally statistically significant decrease of 13% compared to federal ULSD and Fed/HVO-20 showed a marginally statistically significant increase of 14% compared to CARB ULSD. Reductions in CH_4 emissions for CARB/WCO-20 on the order of 13% at a marginally statistically significant level and 15% at a statistically significant level were also seen compared to Fed/AFME-20 and Fed/HVO-20, respectively. For the hot-start phase, the results showed statistically significant increases in CH_4 emissions of 22%, 21%, and 27%, respectively, for Fed/HVO-20 compared to CARB ULSD, Fed/SME-20, and Fed/WCO-20, while CARB/WCO-20 showed a marginally statistically significant reduction of 17% compared to Fed/HVO-20.

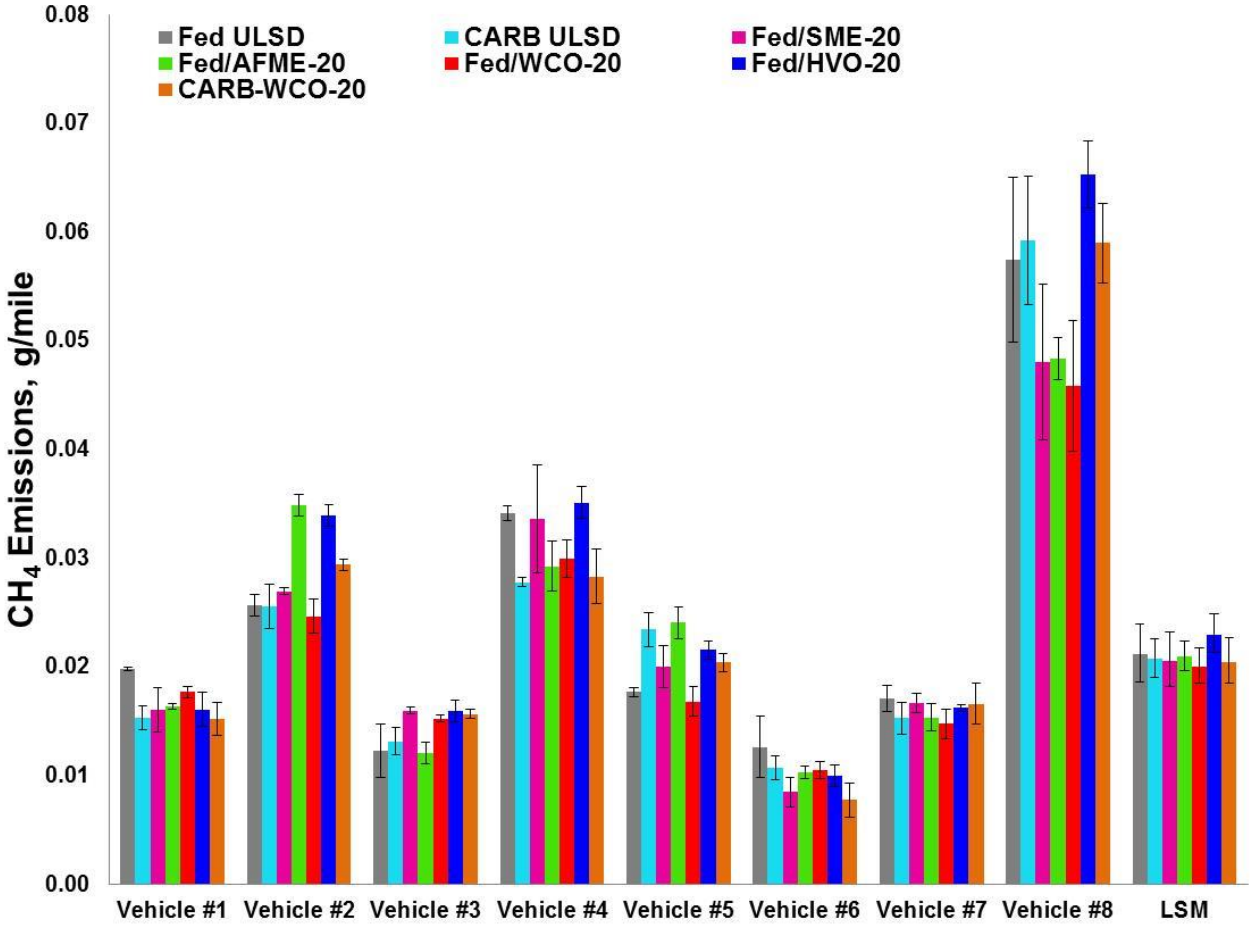


Figure 3-3: Weighted CH_4 emissions over the FTP

3.2 CO Emissions

CO emissions are shown in Figure 3.4. For the weighted CO emissions, the results revealed a statistically significant decrease of 31% and a marginally statistically significant decrease of 18% for CARB ULSD and CARB/WCO-20, respectively, compared to Federal ULSD. Compared to CARB ULSD, the blends of Fed/SME-20, Fed/AFME-20, Fed/WCO-20, and Fed/HVO-20 showed statistically significant increases in CO emissions on the order of 52%, 22%, 40%, and 26%, respectively. The blends of Fed/AFME-20 and CARB/WCO-20 showed statistically significant decreases in CO emissions on the order of 19% and 22%, respectively, compared to Fed/SME-20, while a 17% decrease was also seen for Fed/HVO-20 compared to Fed/SME-20 at a marginally statistically significant level.

For the cold-start phase of the FTP, the results showed statistically significant decreases in CO emissions of 31% and 18%, respectively, for CARB ULSD and CARB/WCO-20 relative to Federal ULSD. For the blends of Fed/SME-20, Fed/AFME-20, Fed/WCO-20, and Fed/HVO-20, cold-start CO emissions showed statistically significant increases of 53%, 23%, 41%, and 24%, respectively, compared to CARB ULSD. Emissions of CO also showed statistically significant reductions on the order of 19%, 19%, and 23% for Fed/AFME-20, Fed/HVO-20, and CARB/WCO-20, respectively, compared to Fed/SME-20. CO emissions did not show any strong fuel effects for the hot-running and hot-start phases of the FTP cycle.

CO emissions tend to be relatively low in diesel engine combustion due to the lean operation diesel engines. The use of biodiesel in diesel engines can reduce CO emissions because of its higher oxygen content, which favors more complete combustion. In addition, the higher cetane number of some saturated biodiesel fuels and the hydrogenated vegetable oil contribute to lower (engine-out) CO. Several studies reported reductions in CO emissions with biodiesel blends (Di et al., 2009; Bakeas et al., 2011a; Nikanjam et al., 2011) and with HVO blends (Murtonen et al., 2009; Pflaum et al., 2010) relative to regular ULSD. In contrast, several chassis dynamometer studies have shown trends of increasing CO emissions with increasing biodiesel percentage in the fuel blend (Durbin et al., 2000; Rose et al., 2010; Fontaras et al., 2009; Fontaras et al., 2010; Bannister et al. 2010). This study's results showed stronger differences between the CARB ULSD and the Federal ULSD compared to the addition of biodiesel. Most biodiesel blends with Federal ULSD showed increased CO emissions relative to the CARB ULSD, but a greater tendency for reduced CO emissions relative to the Federal ULSD. In addition, similar to THC emissions, the more unsaturated Fed/SME-20 blend systematically led to higher CO emissions than the other biodiesel blends.

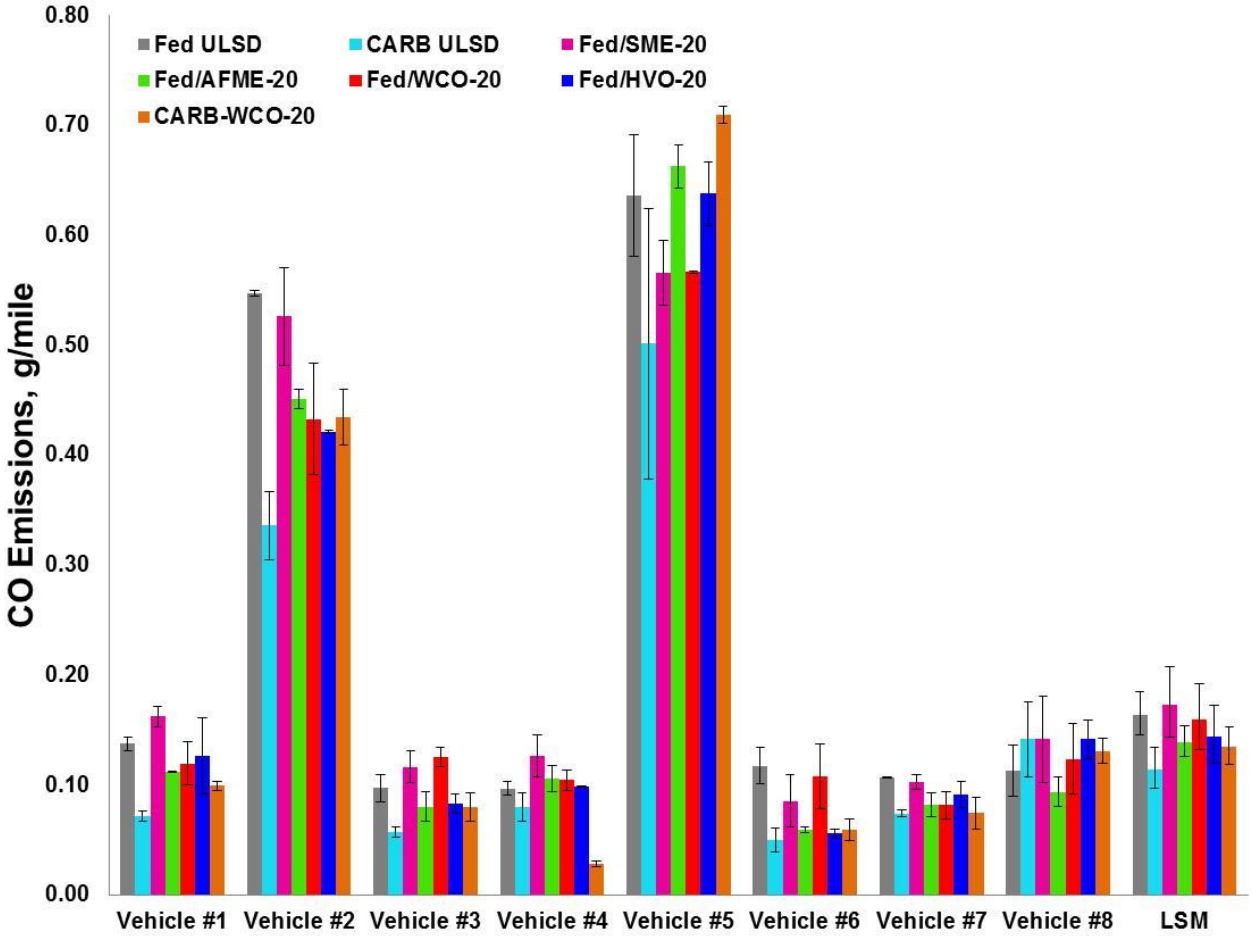


Figure 3-4: Weighted CO emissions over the FTP

3.3 NO_x Emissions

Nitrogen oxides (NO_x) are one of the toughest pollutants to control in a diesel engine. They consist mostly of nitric oxide (NO) and nitrogen dioxide (NO_2), and play an important role in the ground-level atmospheric ozone formation. Formation of NO_x is strongly dependent on temperature (thermal NO_x), residence time of the mixture at high temperatures, and local concentration of oxygen. Other contributing factors are injection timing, fuel type, and fuel properties. Average NO_x emissions over the FTP are shown in Figure 3.5. Statistical analysis of the results showed that neither the weighted NO_x nor NO_x from any individual phase of the FTP were influenced by the test fuels.

Over the years, numerous studies have focused on the impact of biodiesel on NO_x emissions, with most studies showing either increases in NO_x with biodiesel or no change in NO_x emissions. Most of the studies in this area have focused on heavy-duty engines where NO_x increases with biodiesel have been attributed to a variety of factors including, but not limited to, the stoichiometry during combustion, higher adiabatic flame temperatures, the impact of lower energy biodiesel on the engine control system, or reduced radiative heat losses (Giakoumis et al., 2012; Hoekman and Robbins, 2012). Studies of light-duty diesel vehicles/engines have shown less consistent NO_x impacts with biodiesel. Some studies of light-duty vehicles have shown lower NO_x emissions with biodiesel over the more lightly-loaded FTP and NEDC which could be attributed to lower engine loads than are usually seen for test cell engines (Staat and Gateau, 1995; Fontaras et al., 2010b; Bakeas et al., 2011b). In the present study, the vehicles were equipped with SCR aftertreatment, which is currently the most prevalent technology for reducing NO_x emissions. Any combustion process-related impacts on NO_x emissions were likely overshadowed by the significant reductions from the advanced NO_x aftertreatment controls leading to a lack of any significant differences in NO_x emissions between fuels. Differences in engine-out NO_x emissions may produce differences in urea Diesel Exhaust Fluid (DEF) consumption rate. However, there was no attempt to measure DEF consumption rate in this study. While reductions in NO_x emissions for some biodiesel blends and vehicle combinations relative to both ULSDs were observed, as well as some NO_x increases for the unsaturated biodiesel blend relative to the other biofuel blends and ULSDs, these phenomena were not consistent throughout the fleet and the differences were not statistically significant.

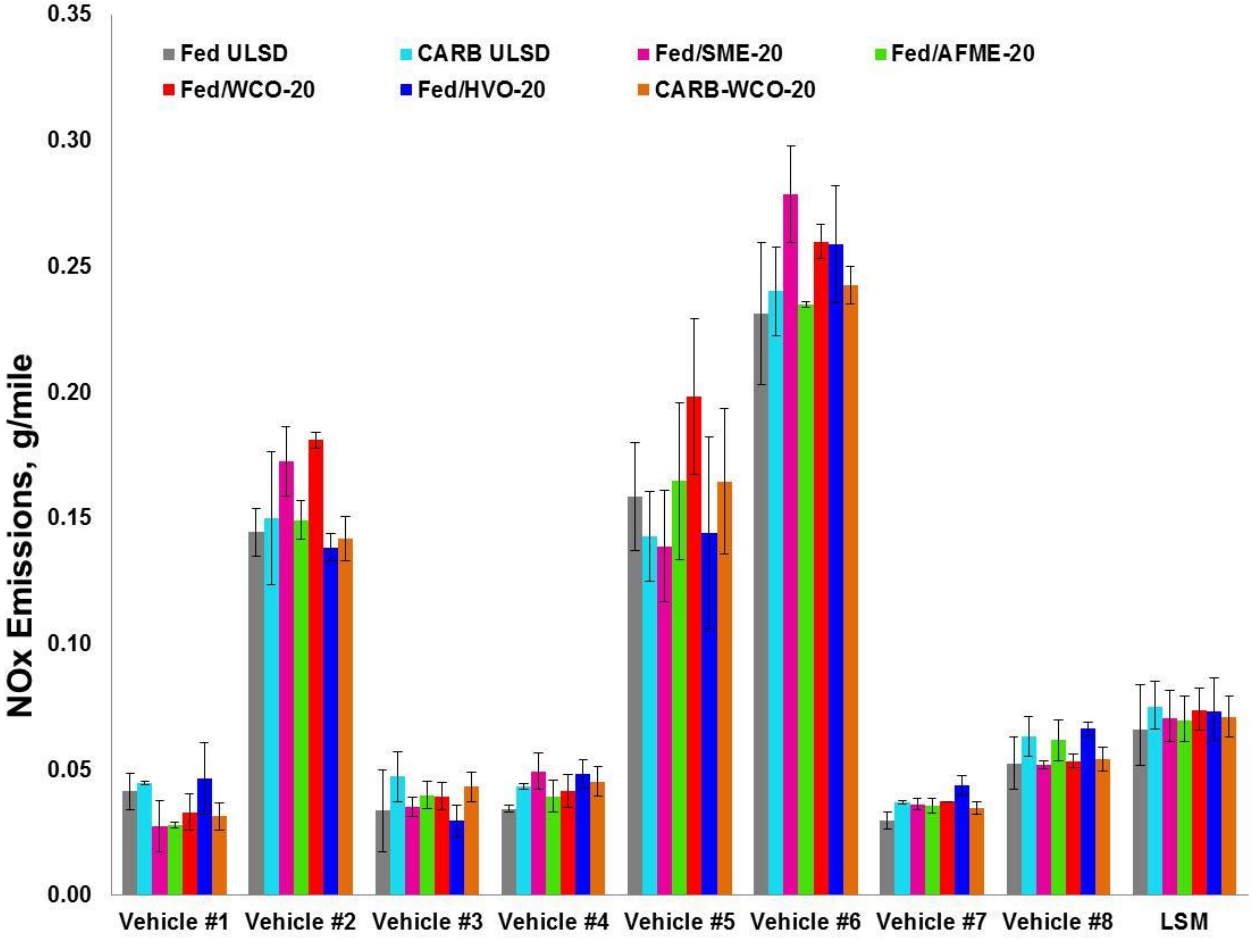


Figure 3-5: Weighted NO_x emissions over the FTP

3.4 CO_2 Emissions and Fuel Economy

CO_2 emissions are shown in Figure 3.6. An increasing trend in CO_2 emissions was observed with most of the biodiesel blends compared to the baseline Federal and CARB fuels. For the weighted CO_2 emissions, the results showed statistically significant increases of 1.9% for Fed/SME-20 and 2.3% for Fed/WCO-20 compared to Federal ULSD and of 1.7% for Fed/WCO-20 compared to CARB ULSD. The blend of Fed/WCO-20 showed a statistically significant increase in CO_2 emissions of 1.7% compared to Fed/AFME-20, whereas the blends of Fed/HVO-20 and CARB/WCO-20 showed statistically significant decreases of 2.5% and 1.7%, respectively, compared to Fed/WCO-20.

For the cold-start phase, statistically significant decreases in CO_2 emissions were seen for Fed/HVO-20 (2.8%) and CARB/WCO-20 (2.4%) compared to Fed/Fed/WCO-20. For the hot-running phase of the FTP, statistically significant increases in CO_2 emissions of 2.3% for Fed/SME-20 and 2.6% for Fed/WCO-20 compared to Federal ULSD and 1.8% for Fed/WCO-20 compared to CARB ULSD were observed. The Fed/HVO-20 blend was also lower at a statistically significant level on the order of 2.1% and 2.4%, respectively, compared to Fed/SME-20 and Fed/WCO-20. For the hot-start CO_2 emissions, the results showed marginally statistically significant increases of 2.3% for Fed/SME-20 and 2.4% for Fed/WCO-20 compared to Federal ULSD, while Fed/HVO-20 showed a statistically significant decrease of 2.4% for both Fed/SME-20 and Fed/WCO-20.

Available studies in the literature report both increases and decreases in CO_2 emissions with the application of biodiesel fuels. Previous studies conducted on Euro 3 and Euro 4 light-duty vehicles running on different biodiesel blends showed some increases in CO_2 emissions or insignificant differences when compared to regular ULSD (Rose et al., 2010; Karavalakis et al., 2011a; Kousoulidou et al., 2012). According to the authors, a contributing factor for the higher CO_2 emissions could be due to difference in H:C ratios for biodiesel compared to that of petroleum diesel, as the presence of a carbonyl group in the methyl ester interrupts the H to C sequence in the fuel. As a result, more carbon is injected into the cylinder for the same energy content. Taking into account a typical methyl ester speciation, a neat biodiesel delivers approximately 1.8% more carbon into the cylinder for the same energy as petroleum diesel fuel. The increase in carbon per unit of energy leads to a proportional increase of CO_2 emissions. In addition, the lower energy content of biodiesel and its blends compared to petroleum diesel forces the engine to operate at a higher ‘apparent’ load, i.e., requiring more fuel to be injected per stroke. This higher apparent load may lead the engine to operate at a different point in the engine map, resulting to a different thermodynamic efficiency.

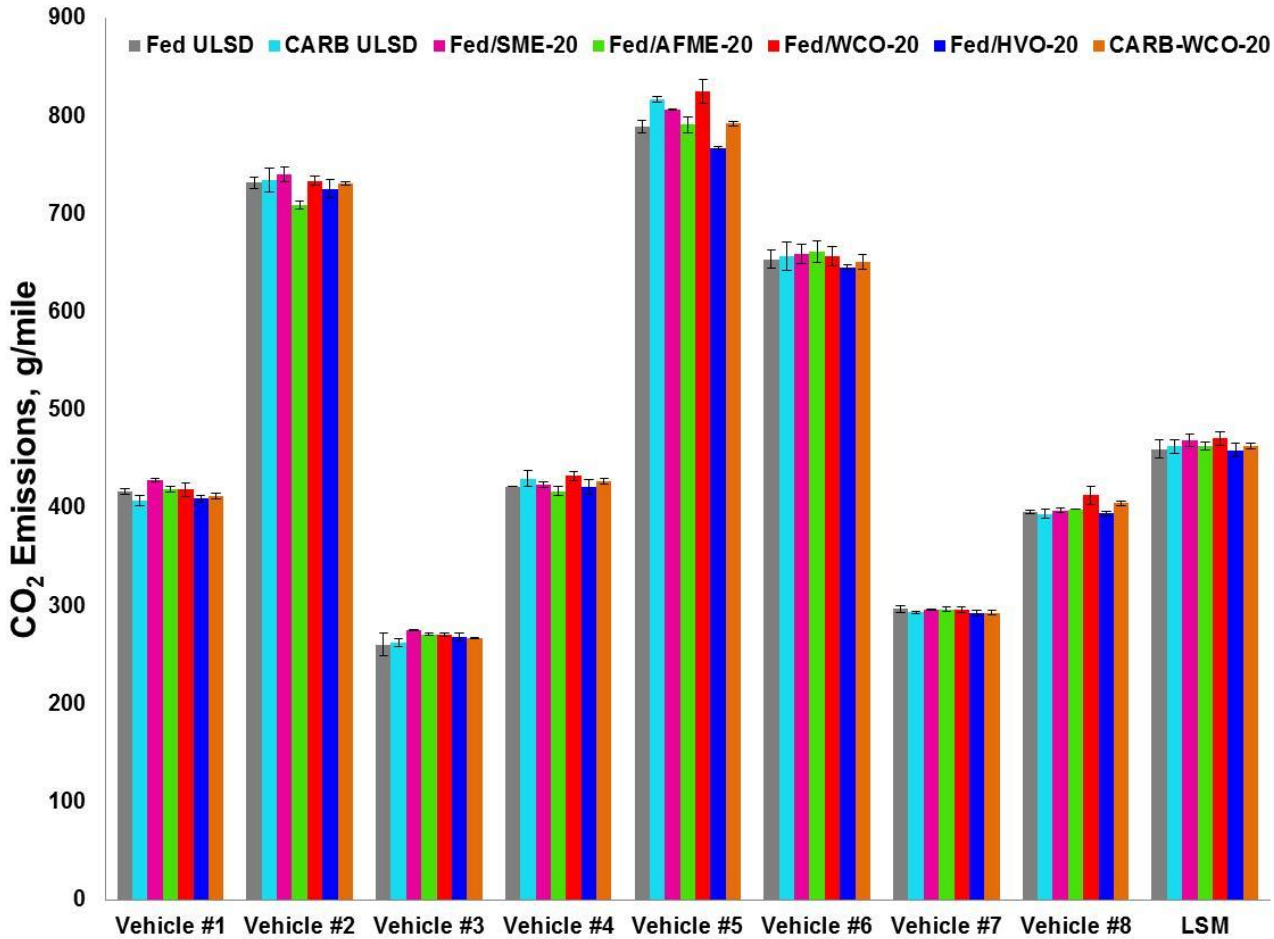


Figure 3-6: Weighted CO_2 emissions over the FTP

The fuel economy results for the different test vehicles are presented in Figure 3.7. For this study, fuel economy was calculated based on the carbon balance method and the unique properties for each different test fuel, rather than the standard EPA equation. The carbon balance equation (shown below) more directly accounts for the differences in energy content between different fuels, which are somewhat normalized out in the standard EPA equation.

$$Fuel\ Economy\ Carbon\ Balance = \frac{CWF \times sp.gr \times 3781.8}{(CWF \times THC\left(\frac{g}{mile}\right)) + (0.429 \times CO\left(\frac{g}{mile}\right)) + (0.273 \times CO2\left(\frac{g}{mile}\right))}$$

Where:

3781.8: Density of water at 60 ˚F in g/gals

THC: THC emission rate (g/mile)

CO: CO emission rate (g/mile)

CO_2: CO_2 emission (g/mile)

CWF: Carbon weight fraction of the test fuel

sp.gr: Specific gravity of the test fuel

For the weighted fuel economy, the results showed some strong effects for the Federal ULSD compared to CARB ULSD and the biofuel blends, but CARB ULSD did not show strong effects compared to biodiesel blends. Compared to Federal ULSD, weighted fuel economy showed

statistically significant decreases of 3.7%, 4.2%, 4.2%, 4.8%, 2.8%, and 5.7% for CARB ULSD, Fed/SME-20, Fed/AFME-20, Fed/WCO-20, Fed/HVO-20, and CARB/WCO-20. As expected, the CARB ULSD and the HVO blend showed smaller differences in fuel economy compared to the Federal ULSD. It is interesting to note that comparing the gross heating values for the test fuels, their energy contents are lower by 2.4% for Fed/SME-20, 2.5% for Fed/AFME-20, 2.6% for Fed/WCO-20, and 1.3% for CARB/WCO-20 compared to Federal ULSD. On the other hand, CARB ULSD and Fed/HVO-20 blend showed higher gross heating values by 1.2% and 0.8%, respectively, compared to Federal ULSD. For CARB ULSD, the only statistically significant effect in weighted fuel economy was observed for CARB/WCO-20 blend, which showed a reduction of 2.1%. The blend of Fed/HVO-20 showed a statistically significant increase of 2.1% compared to Fed/WCO-20, while CARB/WCO-20 showed a statistically significant decrease of 3.0% compared to Fed/HVO-20.

For the cold-start phase, fuel economy results showed statistically significant decreases of 3.4%, 3.3%, 3.8%, 4.3%, and 4.6% for CARB ULSD, Fed/SME-20, Fed/AFME-20, Fed/WCO-20, and CARB/WCO-20 compared to Federal ULSD, while the non-oxygenated Fed/HVO-20 showed a marginally statistically significant decrease of 2.1% compared to Federal ULSD. The blend of Fed/HVO-20 showed a marginally statistically significant increase in fuel economy of 2.3% compared to Fed/WCO-20 and CARB/WCO-20 showed a statistically significant decrease of 2.5% compared to Fed/HVO-20. Similar to the weighted and cold-start fuel economy results, for the hot-running phase, fuel economy showed statistically significant decreases of 3.9%, 4.5%, 4.5%, 5.2%, 3.2%, and 6.4%, respectively, for CARB ULSD, Fed/SME-20, Fed/AFME-20, Fed/WCO-20, Fed/HVO-20, and CARB/WCO-20 compared to Federal ULSD. Compared to CARB ULSD, the only statistically significant decrease was seen for CARB/WCO-20 (2.7%). A marginally statistically significant increase on the order of 2.1% and a statistically significant decrease of 3.4% was seen for the Fed/HVO-20 compared to Fed/WCO-20 and CARB/WCO-20, respectively. For the hot-start phase of the FTP, fuel economy results showed statistically significant decreases of 3.6%, 4.7%, 3.9%, 4.6%, and 5.6%, respectively, for CARB ULSD, Fed/SME-20, Fed/AFME-20, Fed/WCO-20, and CARB/WCO-20 compared to Federal ULSD, while the non-oxygenated Fed/HVO-20 showed a marginally statistically significant decrease of 2.8% compared to Federal ULSD. A marginally statistically significant decrease of 2.9% was also seen for CARB/WCO-20 compared to Fed/HVO-20.

The reductions in fuel economy with the biodiesel blends are in line with previous studies (Rose et al., 2010; Karavalakis et al. 2010a; Bakeas et al., 2011a) and can be attributed to the lower energy content of biodiesel compared to petroleum diesel. This trend is consistent when comparing the biodiesel blends with the Federal ULSD, i.e., the fuel with the highest energy content, but this trend less consistent when comparing the biodiesel blends with federal diesel to CARB ULSD, due to the lower energy content of the CARB ULSD compared to the Federal ULSD.

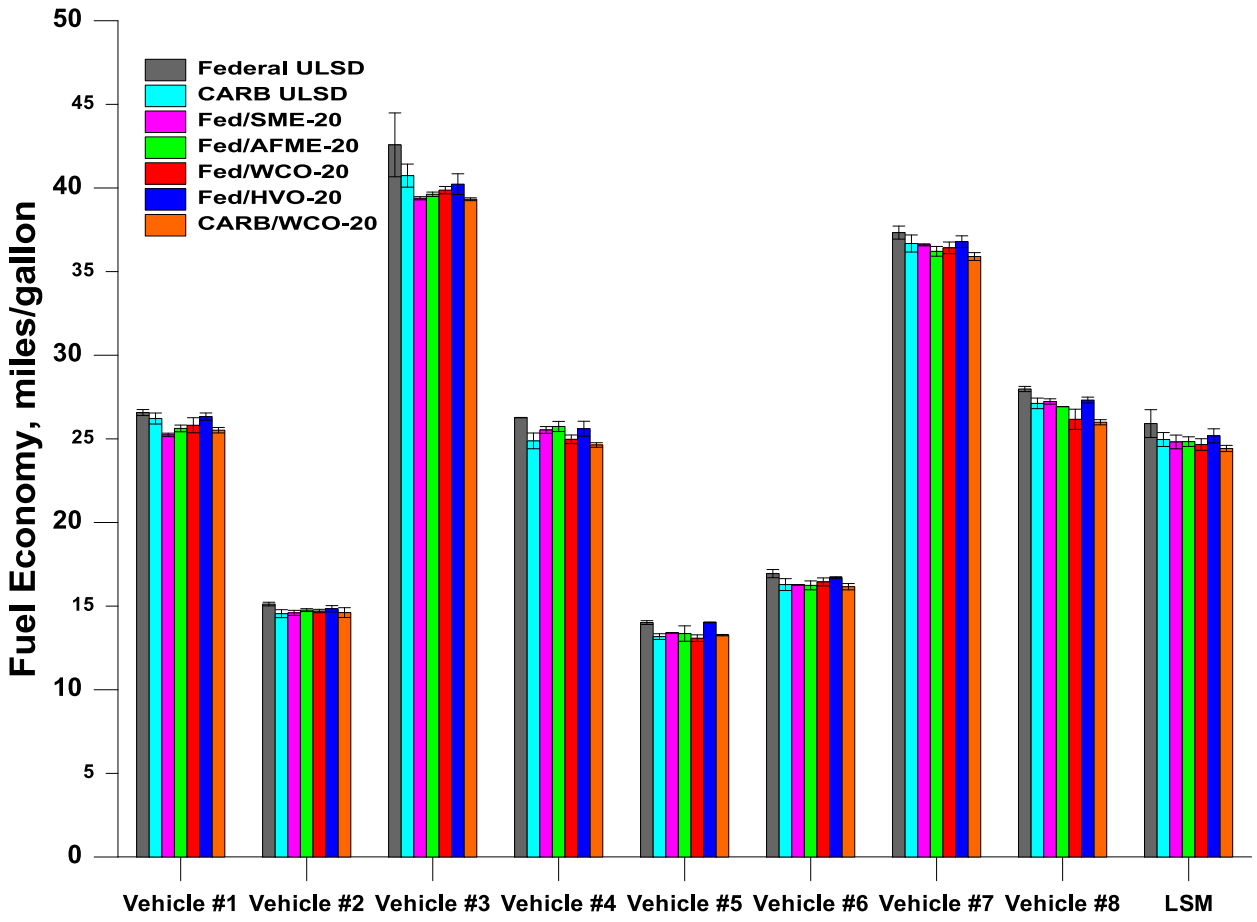


Figure 3-7: Average fuel economy results based on the carbon balance method

3.5 PM Emissions

PM mass emissions are shown in Figure 3.8. PM emission rates ranged from approximately 0.18 to 2.65 mg/mi, consistent with the lower PM emission rates that are typically seen for light-duty diesel vehicles equipped with DPF aftertreatment (Fontaras et al., 2014; May et al., 2014). The PM emission rates for the cumulative samples were, in most cases, well above the tunnel background level, which is provided as the rightmost bar in the figure. The PM emissions rates for the vehicles are shown without subtraction for the tunnel background. The larger error bars for some vehicle/fuel combinations can be attributed to test-to-test variability, as the typical accuracy of the PM measurement itself is approximately ±5-15%. For this study, PM mass emissions did not show any statistically significant differences between the test fuels. The results showed both increases and decreases in PM mass emissions with the biofuel blends compared to both ULSD fuels, with these differences not being consistent or statistically significant between fuels for the fleet as a whole.

In understanding the PM emission results, it is important to note that many of the biodiesel emissions studies to date have been conducted on vehicles/engines without extensive aftertreatment systems for PM reductions. In general, most of these studies with light-duty or heavy-duty engines have found decreasing PM mass emissions during transient operations for biodiesel blends (McCormick et al., 2001; Lapuerta 2008b; Kousoulidou et al., 2010), although there are several chassis dynamometer studies conducted on light-duty vehicles fueled with various biodiesel blends that have shown increases in PM emissions relative to regular ULSD fuels (Peterson and Reece, 1996; Durbin et al., 2000; Martini et al., 2007; Fontaras et al., 2009; Karavalakis et al., 2009; Bakeas et al., 2011). Various reasons have been documented to explain

the reductions in PM emissions with the use of biodiesel fuels, with the primary contributing factor for the PM decrease being the presence of oxygen in the methyl ester molecule. Oxygenated fuels, such as biodiesel blends, possess the ability to reduce locally fuel-rich regions and limit soot nucleation early in the formation process, thus reducing PM emissions. In addition, the absence of aromatic compounds in biodiesel fuels, which are generally considered to act as soot precursors, may also be a reason for the reductions in PM emissions compared to the baseline diesel fuels (Lapuerta et al., 2008a). For studies that have shown increases in PM emissions for light-duty vehicles, where cold-start emissions are a significant portion of the overall PM emissions, it is possible that certain physical properties of biodiesel can prevail over its increased oxygen content (Fontaras et al. 2009; Bakeas et al. 2011; Karavalakis et al. 2009; Martini et al. 2007). For example, the higher initial boiling point of biodiesel compared to regular petroleum ULSD, which leads to more difficult fuel evaporation at low temperatures, and the higher viscosity of biodiesel, which reduces the rate of spray atomization, could both contribute to increased PM emissions.

Biodiesel emissions studies for vehicles/engines equipped with advanced aftertreatment controls, and particularly DPFs, are more limited. Studies of heavy-duty engines and vehicles equipped with DPFs have generally shown that biodiesel does not have a strong influence on PM emissions given the already significant reductions in PM emissions that are obtained from the DPF (Lammert et al. 2012; Williams et al. 2011a; Olatunj et al. 2010; Gsyel et al. 2014; Hajbabaei et al. 2013). For a retrofit DPF equipped heavy-duty engine, however, Williams et al. (2006) showed that PM reductions of 27% for biodiesel blend compared to ULSD could still be obtained along with a significant lowering of balance point temperature and an increase in regeneration rate. Williams et al. (2010) also found that the presence of oxygen can promote faster regenerations and greater soot reactivity for a catalyzed DPF. Studies of light-duty vehicles with more advanced aftertreatment systems are more limited. There have also been a number of studies that have looked at the potential impact of impurities in biodiesel on longer term durability of DPFs and lube oil dilution, but these issues are not relevant for comparison with the current study, which was of short duration (Williams et al. 2011; Williams et al. 2013; He et al. 2011).

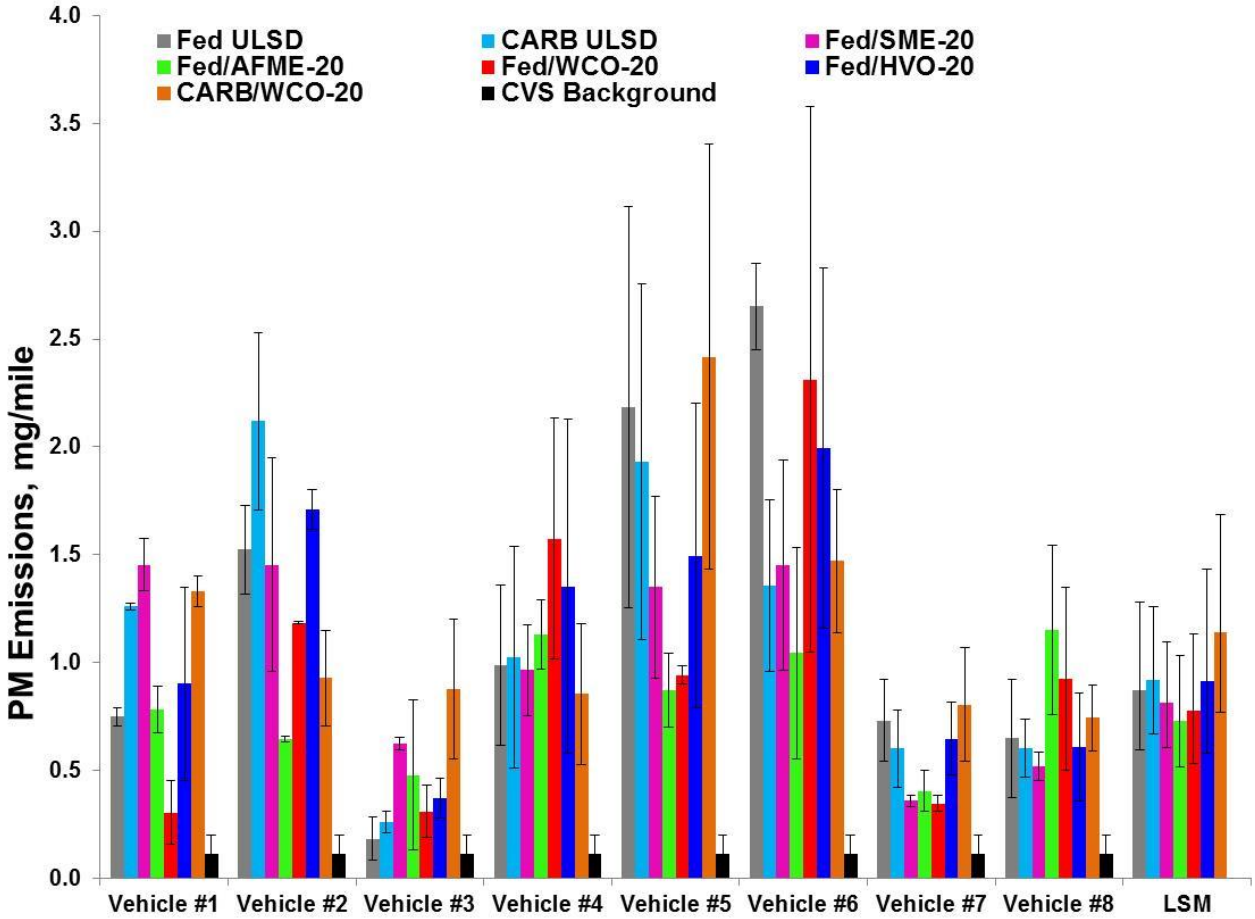


Figure 3-8: PM mass emissions over the FTP

3.6 Particle Number Emissions

Total particle number emissions, expressed in particles/mile, are shown in Figure 3.9. Statistical analysis was conducted on both the cold-start and the weighted particle number emissions for the fleet as a whole. The results did not reveal any statistically significant different between the test fuels for either the cold-start or the weighted particle number emissions. It should be noted that particle number emissions for Vehicle #5 and Vehicle #7 were found to be lower than the other test vehicles. In general, some reductions were seen in particle number emissions with the use of biofuel blends for Vehicle #1 and Vehicle #2, but not for the other test vehicles. Particle number emissions showed both increases and decreases with the biofuel blends and largely a lack of fuel trends throughout the fleet. This phenomenon could be ascribed to the presence of the DPF control, which appeared to eliminate any potential engine fuel effect. Similar results, where biodiesel fuel effects have been negligible for DPF equipped engines, have been reported in other studies (Lammert et al., 2012; Williams et al., 2011a), although other studies have seen reductions for biodiesel fuels even at these relatively low particle number levels (Li et al. 2012; Fontaras et al., 2014).

Figure 3.10 (a-h) shows the particle number emissions for each vehicle/fuel combination for each individual phase of the FTP cycle. With the exception of Vehicle #2, particle number emissions were dominated by the cold-start phase of the FTP cycle, where the majority of particle number emissions were produced during the first 200-300 seconds of the cycle. This phenomenon was due to the fact that the engine was cold and the DOC was below its light-off temperature. It is assumed that these elevated particle number emissions during the cold-start might be semi-

volatile materials escaping oxidation as the catalytic converters have not reached the light-off temperature. For the hot-running and hot-start phases of the FTP, particle number emissions for most vehicles were substantially lower than those emitted during cold-start conditions, suggesting higher filtration efficiency of the DPF. It should be noted that during cold-start operation the particle number measurement variability was increased compared to phases 2 and 3 of the FTP. It was also observed that the use of biodiesel blends increased the variability of the particle number emissions during the cold-start phase when compared to both ULSD fuels. Although there is no clear explanation for this phenomenon, it is theorized that the overall absence of fuel effects were related to changes in the filtration efficiency as the DPF heated up and to the increase of soluble organic fraction (SOF) particles of biodiesel, which somehow affected the measurement variability during cold-start operation.

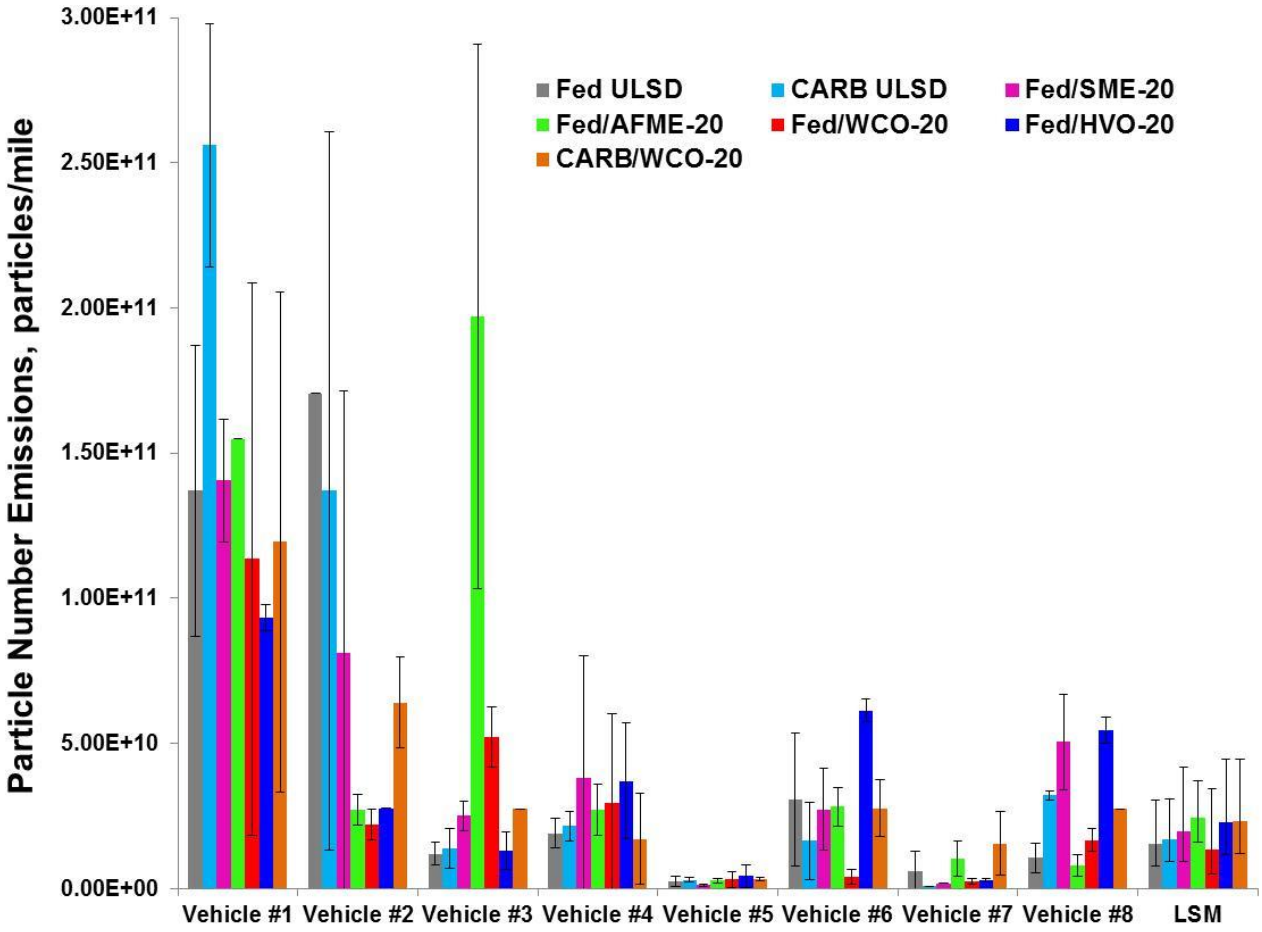
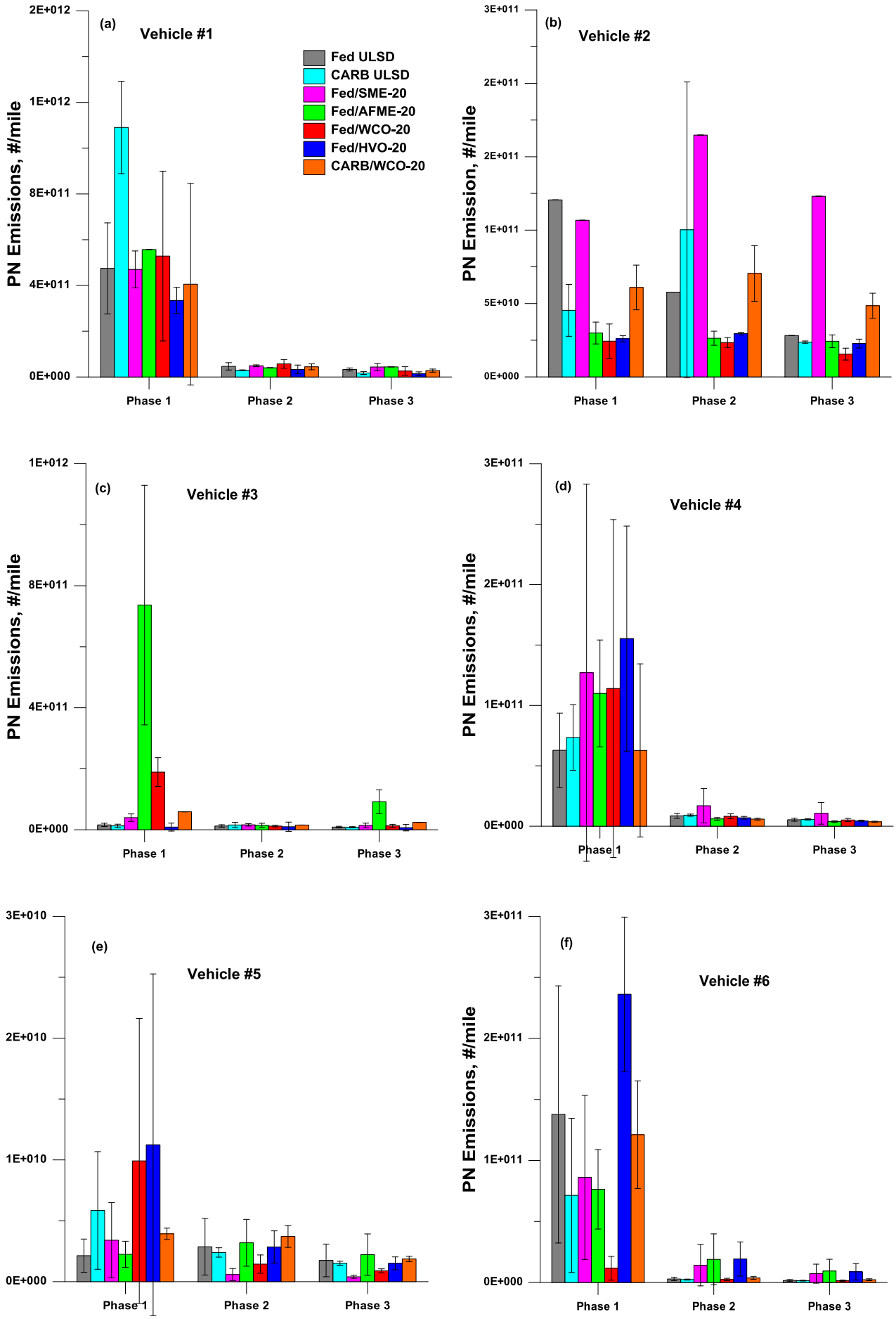


Figure 3-9: Particle number emissions over the FTP


(a)
Vehicle #1
Fed ULSD
CARB ULSD
Fed/SME-20
Fed/AFME-20
Fed/WCO-20
Fed/HVO-20
CARB/WCO-20
PN Emissions, #/mile
2E+012
1E+012
8E+011
4E+011
0E+000
Phase 1
Phase 2
Phase 3
(b)
Vehicle #2
PN Emission, #/mile
3E+011
2E+011
2E+011
1E+011
5E+010
0E+000
Phase 1
Phase 2
Phase 3
(c)
Vehicle #3
PN Emissions, #/mile
1E+012
8E+011
4E+011
0E+000
Phase 1
Phase 2
Phase 3
(d)
Vehicle #4
PN Emissions, #/mile
3E+011
2E+011
1E+011
0E+000
Phase 1
Phase 2
Phase 3
(e)
Vehicle #5
3E+010
2E+010
1E+010
0E+000
Phase 1
Phase 2
Phase 3
(f)
Vehicle #6
PN Emissions, #/mile
3E+011
2E+011
1E+011
0E+000
Phase 1
Phase 2
Phase 3

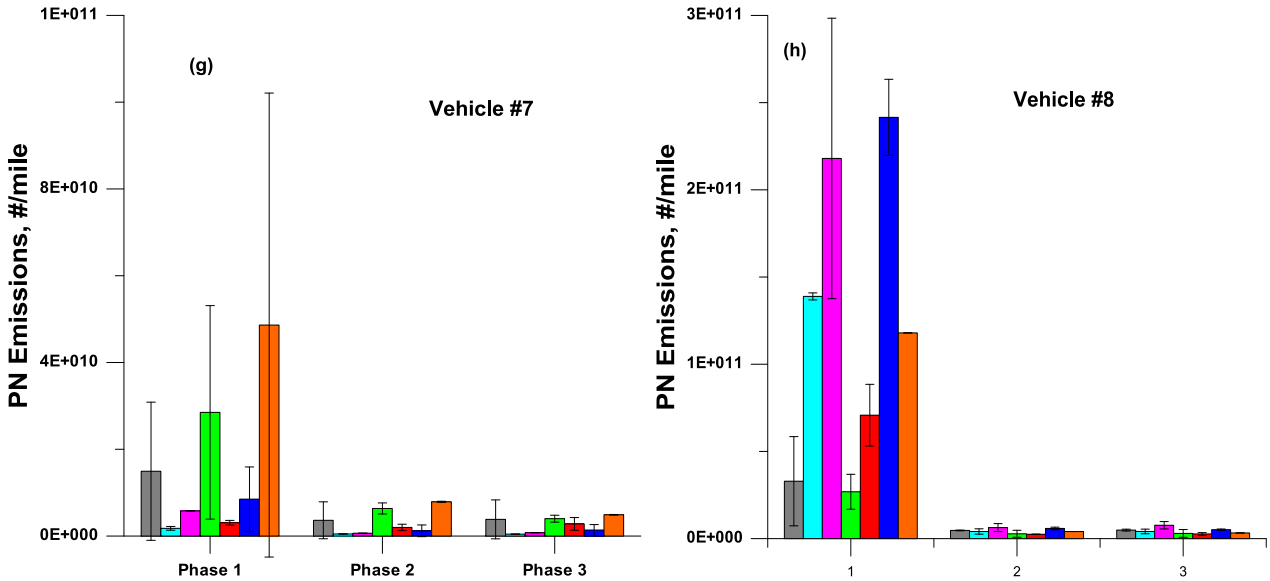


Figure 3-10 (a-h): Particle number emissions for each individual phase of the FTP

3.7 Particle Size Distributions

Average EEPS particle size distributions (PSDs) for Vehicle #1 through Vehicle #8 are shown in Figures 3.11 through 3.18, respectively. It should be noted the EEPS was not available for testing Fed ULSD, Fed/AFME-20, and Fed/WCO-20 for Vehicle #1 and for the Fed/HVO-20 blend for Vehicle #2. For Vehicle #1, all fuels produced size distributions with peaks at 30-50 nm in diameter. The CARB ULSD was found to produce the highest accumulation mode particle concentrations at around 50 nm followed by the CARB/WCO-20 blend. This is somewhat consistent with the higher particle number emissions for the CARB ULSD compared to the biodiesel blends and the renewable diesel blend, as shown in Figure 3.9, and the generally higher PM masses for these two fuels, as shown in Figure 3.8. For Vehicle #2, the differences in PSDs between the test fuels were not as strong, with all fuels showing accumulation mode particles with mobility diameters at ~ 30-40 nm. Similar to Vehicle #1, CARB ULSD and its blend with WCO produced higher accumulation mode particle concentrations than Federal ULSD and the other biofuel blends. The PSDs for Vehicle #3 showed that all fuels produced accumulation mode particles with peaks at around 50 nm in diameter. The Fed/AFME-20 blend exhibited more accumulation mode particles than the other biodiesel blends, the HVO blend, and the reference ULSDs. This is consistent with the higher total particle number emissions for the animal fat biodiesel compared to all other fuels, as shown in Figure 3.9. Vehicle #4 displayed a unimodal distribution with the accumulation mode dominating the PSD for all fuels. The biofuel blends showed higher accumulation mode particle counts than both ULSD fuels, with the non-oxygenated Fed/HVO-20 blend producing higher accumulation mode particles than the biodiesel blends. All fuels showed accumulation mode particles ranging between 45 to 53 nm in diameter.

For Vehicle #5, the PSDs were largely unimodal, with a peak around 90 nm. The PSD profile for the Fed/SME-20 blend showed a bimodal distribution, with the accumulation mode particles peaking at about 107 nm and a smaller number of nucleation mode particles peaking at 14 nm. However, the overall particle counts for this blend were found to be significantly lower compared to all other test fuels for this vehicle and close to the CVS tunnel background limits. In addition, the PSD profile for the Fed/AFME-20 was quite unstable, with nucleation mode

particles peaking at around 9 nm and accumulation mode particles peaking at around 60 nm. It was also found that a second nucleation mode at around 26 nm was formed for this particular blend. Analogous to Vehicle #4, the blends of Fed/HVO-20, Fed/WCO-20 and CARB/WCO-20 showed higher accumulation mode particle concentrations compared to both ULSD fuels. The non-oxygenated HVO blend showed the highest accumulation mode particle counts followed by the Fed/WCO-20 and the CARB/WCO-20 blends. For the biofuel blends, the accumulation mode particles ranged from 94-107 nm in diameter, whereas for the ULSD fuels particle size ranged from 70-93 nm in diameter. Vehicle #6 displayed unimodal distributions with accumulation mode particles ranging from 60 to 80 nm in diameter. The non-oxygenated fuels, namely the ULSD fuels and the HVO blend, produced higher accumulation mode particle concentrations compared to the biodiesel blends. These results are somewhat consistent with the higher PM mass and number emissions for the Fed/HVO-20 compared to the biodiesel blends.

Unlike the other the test vehicles, Vehicle #7 displayed a decidedly bimodal distribution profile for all fuels, with the accumulation mode particles dominating the particle size distribution. The nucleation mode particles ranged from 9-11 nm, while the accumulation mode particles ranged from 40-53 nm in diameter. The biodiesel blends of CARB/WCO-20, Fed/AFME-20, and Fed/SME-20 showed higher accumulation mode particle counts than both reference ULSD fuels, while the HVO blend and Fed/WCO-20 blend showed very low particle counts close to the CVS background levels, consistent with the PM mass emissions for this vehicle as seen in Figure 3.9. Similar to Vehicle #7, Vehicle #8 displayed bimodal distribution profile for all fuels, with the exception of the Fed/SME-20 blend that showed a unimodal distribution with no decidedly accumulation mode peak. Vehicle #8, however, showed much higher concentrations in the nucleation mode range, in contrast to the PSDs for Vehicle #7. The nucleation mode geometric mean particle diameter ranged from 9-20 nm and the accumulation mode mean particle diameter ranged from 52-70 nm. The Fed/SME-20 blend showed the highest nucleation mode particle concentrations followed by the HVO blend, CARB ULSD, and CARB/WCO-20. This result is also consistent with the higher particle number emissions for these fuels. For the accumulation mode particles, the CARB ULSD and HVO blend showed the highest concentrations, followed by the Fed/WCO-20 blend and Federal ULSD.

Although not consistent, the results showed that the soy-based biodiesel blend led to increases for some test vehicles in both nucleation and accumulation mode particle concentrations compared to the other biodiesel blends. Soy-based biodiesel, in particular, contains unsaturated fatty esters, which have been shown to increase nucleation mode particles, possibly because of the emission of organic species with high boiling points, which tend to be more condensable than hydrocarbon components (Schönborn et al., 2009). In addition, the double bonds in the ester molecules are likely to provide a direct path to the formation of carbonaceous soot via the formation of ethene and ethyne during the thermal decomposition of the molecule. Both of these species are known precursor molecules to carbonaceous soot. In general, the particle size distribution results did not show a trend for the fleet as a whole. For some vehicles, biodiesel blends resulted in decreases in accumulation mode particles compared to ULSD fuels. This could be due to the reactivity of surface oxygen groups bonded at edge sites in the methyl ester providing higher rates of oxidation of particulates and to the absence of polyaromatic compounds in the methyl ester, since aromatics are considered precursors for the soot formation process. It is interesting to note that the renewable diesel blend showed higher concentrations of accumulation mode particles for Vehicle #4, Vehicle #5, and Vehicle #6 compared to both baseline ULSDs and the biodiesel blends. Although the renewable diesel contained a negligible amount of aromatics and sulfur, it appears that the absence of oxygen necessary to suppress soot formation played some role in the higher accumulation mode particles.

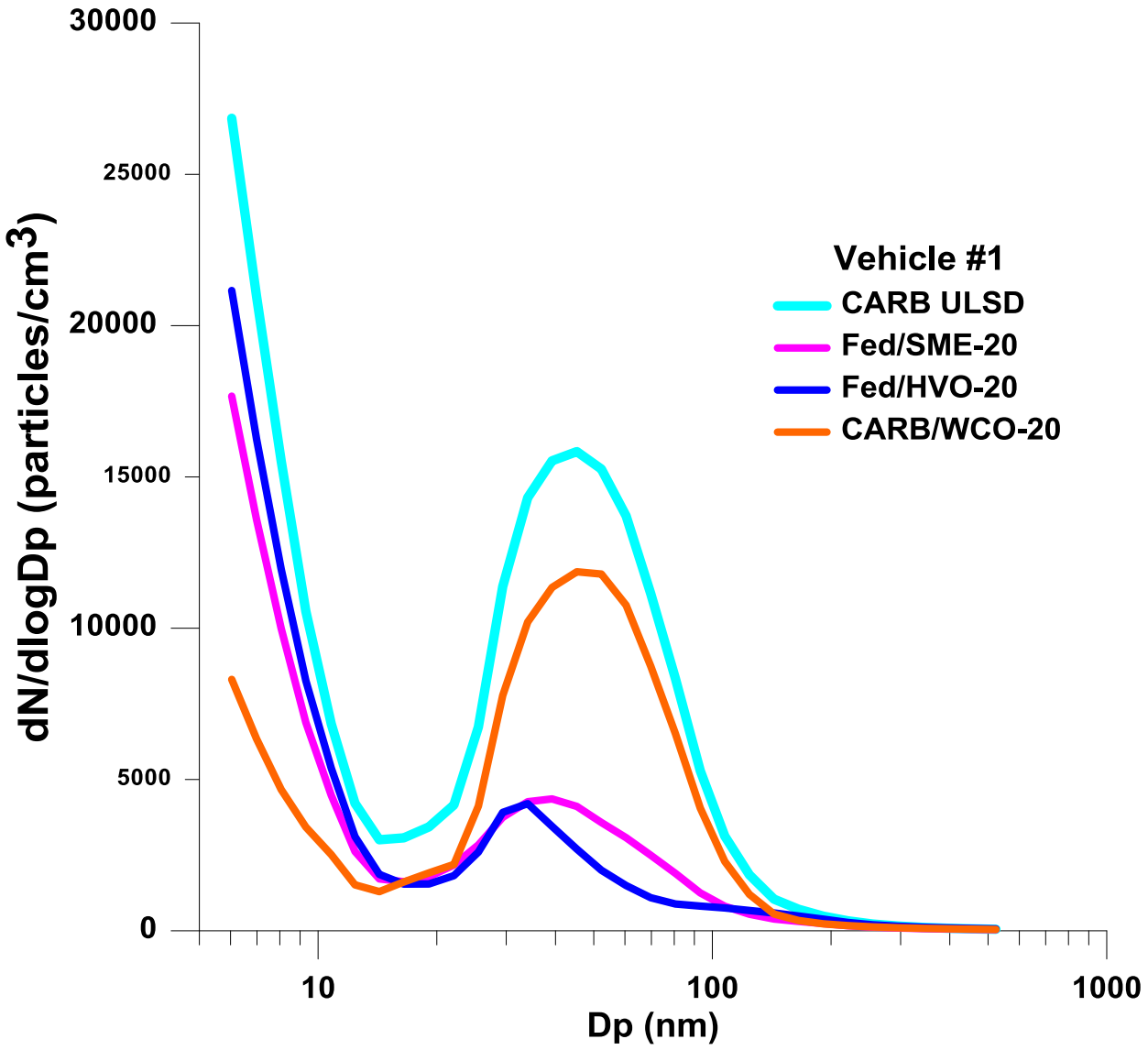


Figure 3-11: Particle size distributions for Vehicle #1 over the FTP

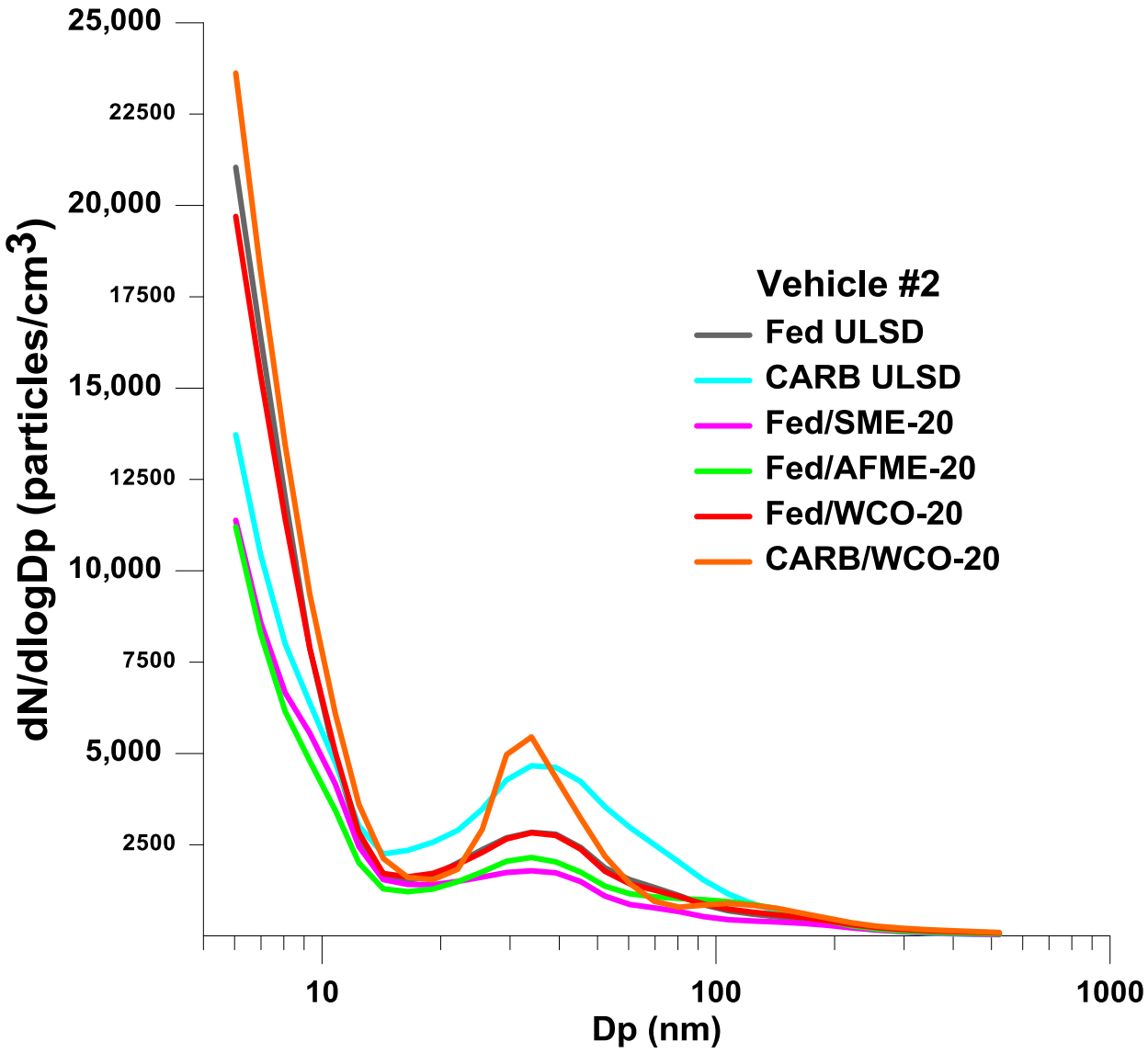


Figure 3-12: Particle size distributions for Vehicle #2 over the FTP

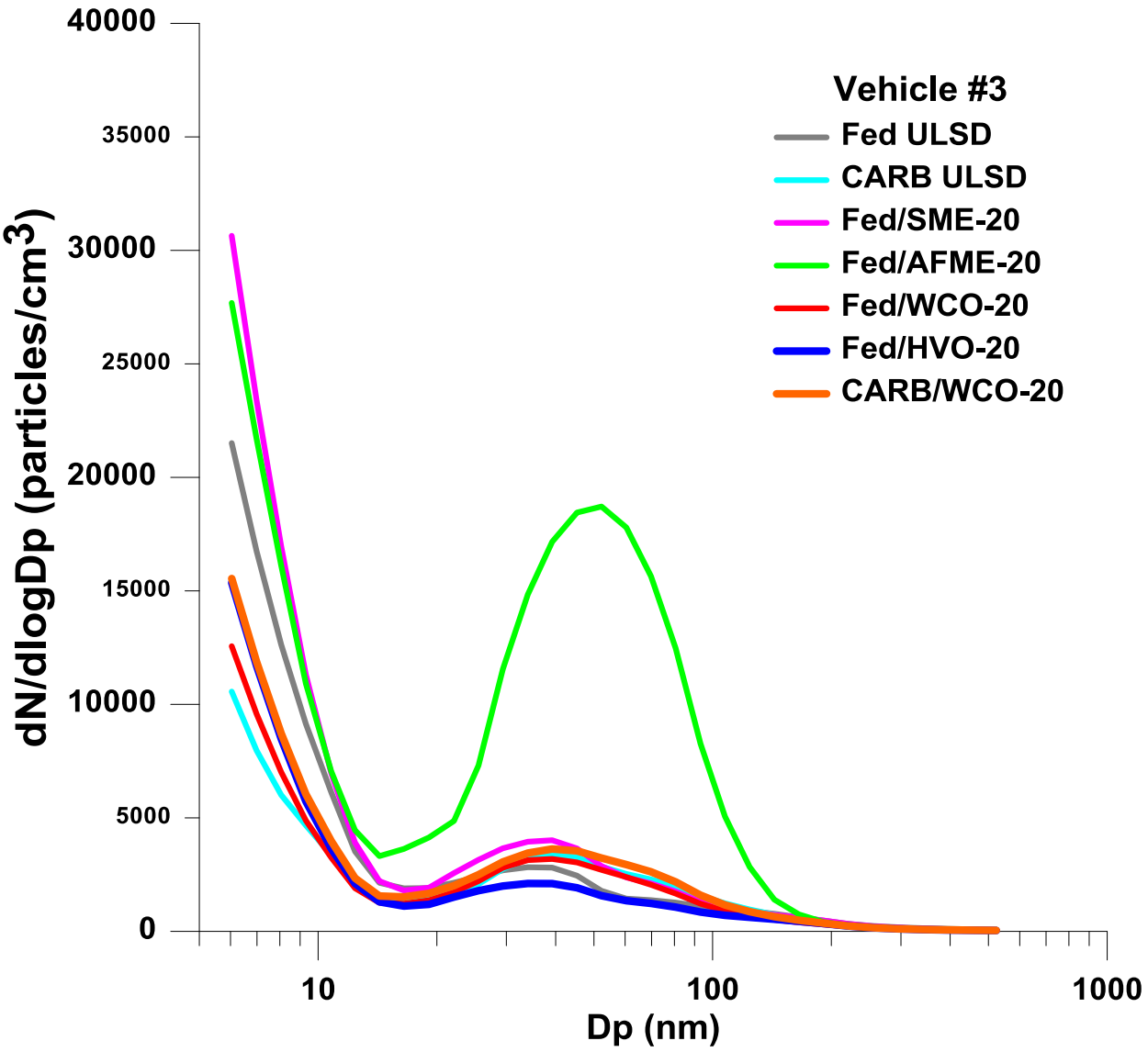


Figure 3-13: Particle size distributions for Vehicle #3 over the FTP

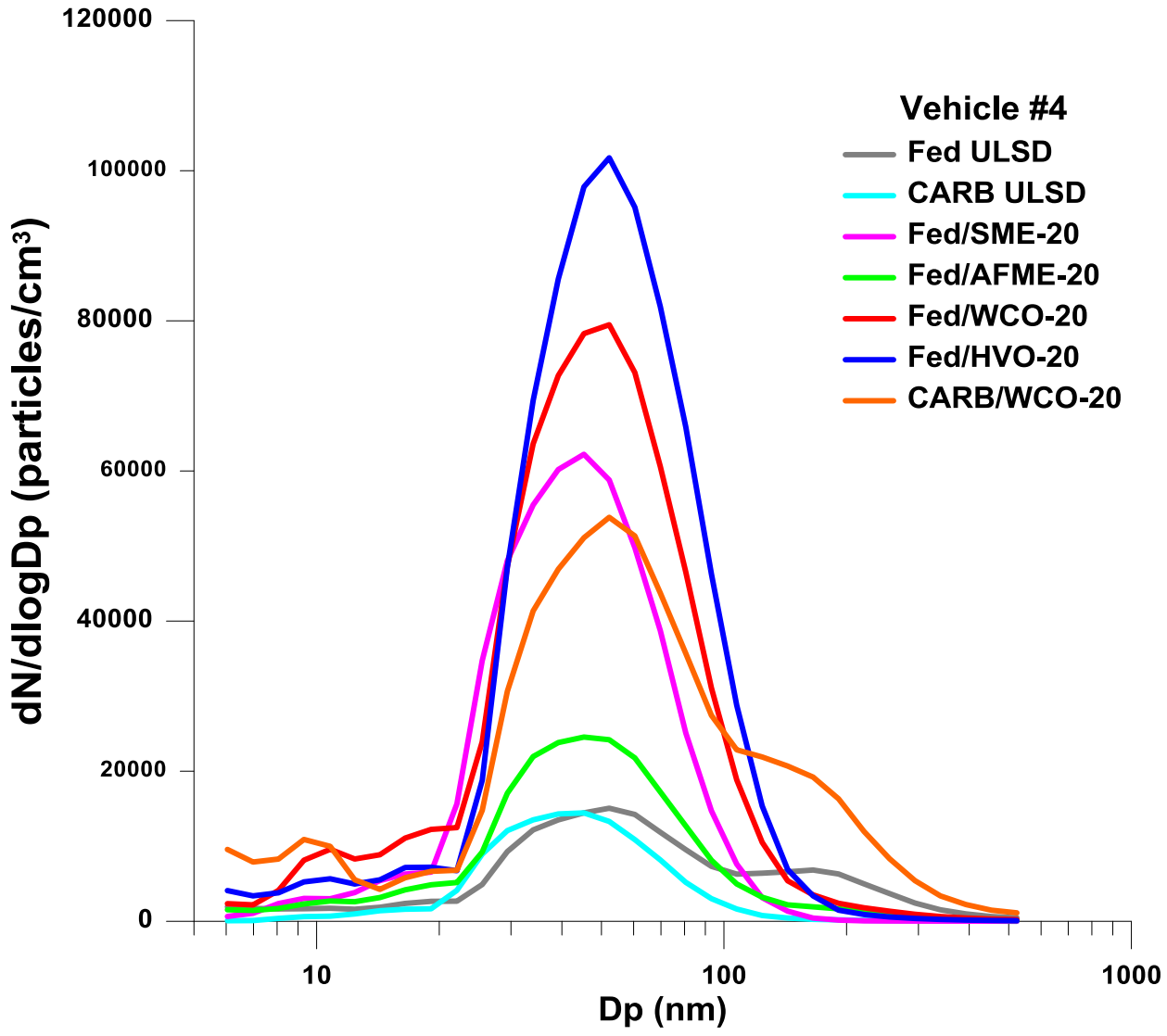


Figure 3-14: Particle size distributions for Vehicle #4 over the FTP

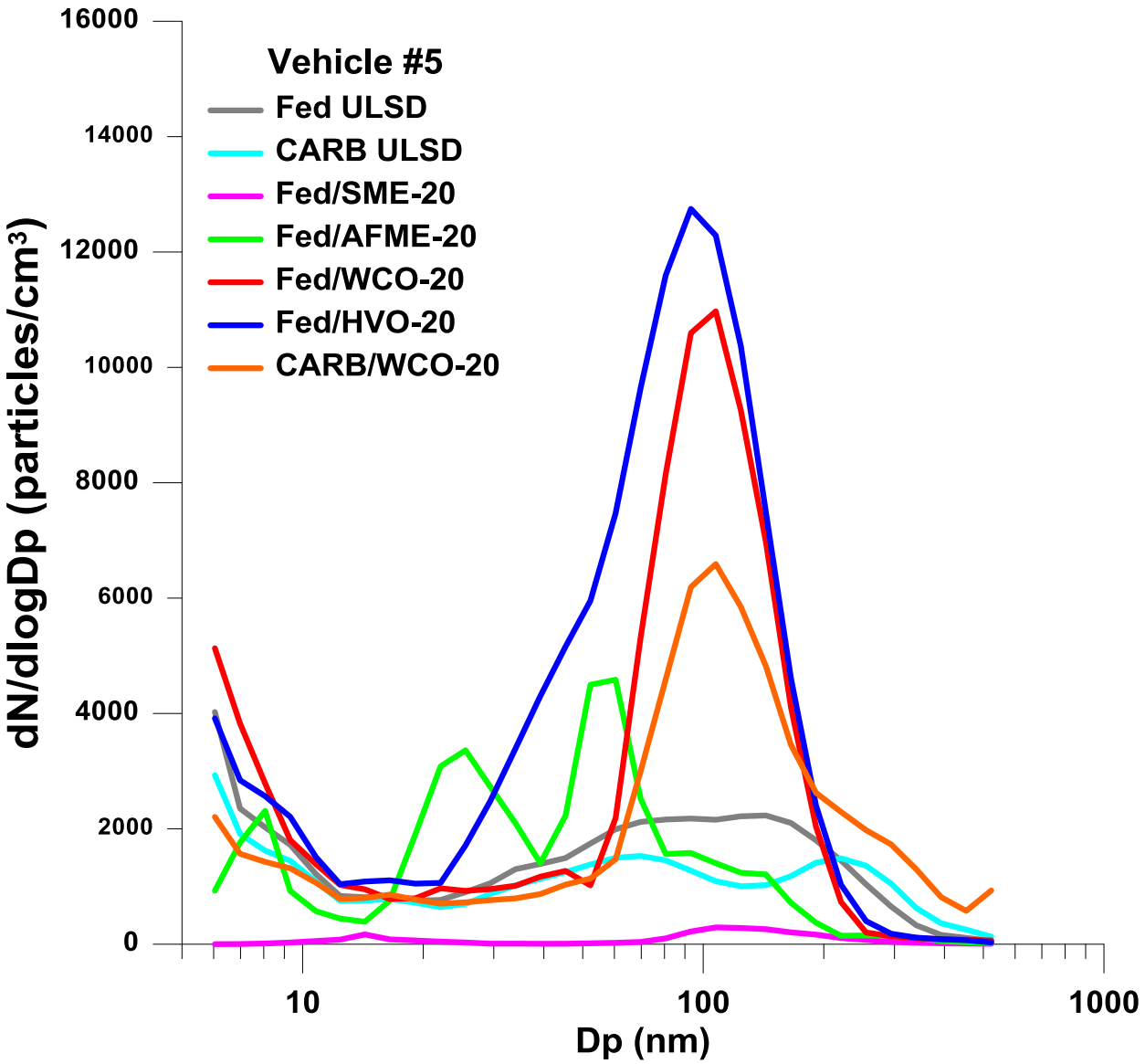


Figure 3-15: Particle size distributions for Vehicle #5 over the FTP

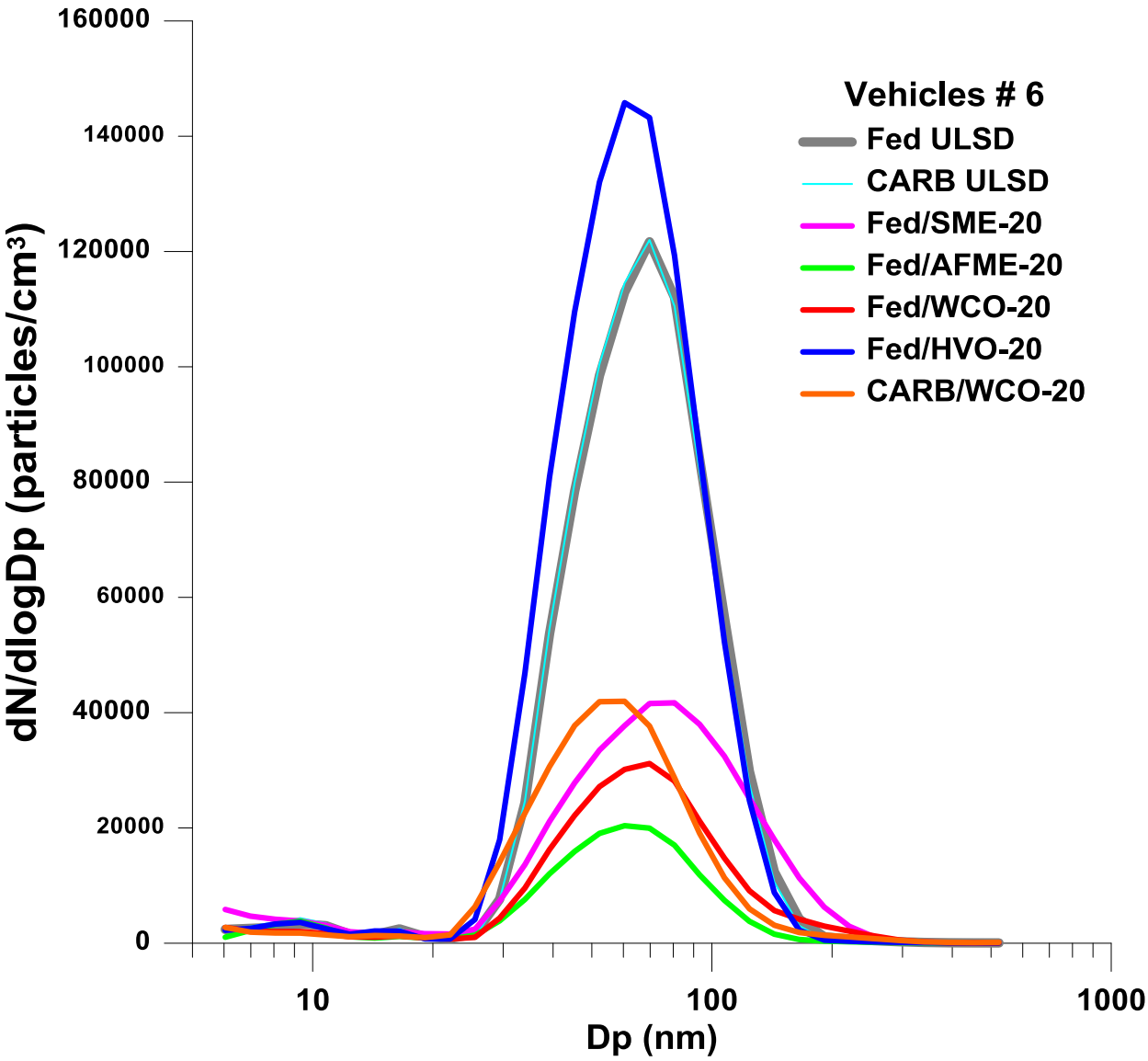


Figure 3-16: Particle size distributions for Vehicle #6 over the FTP

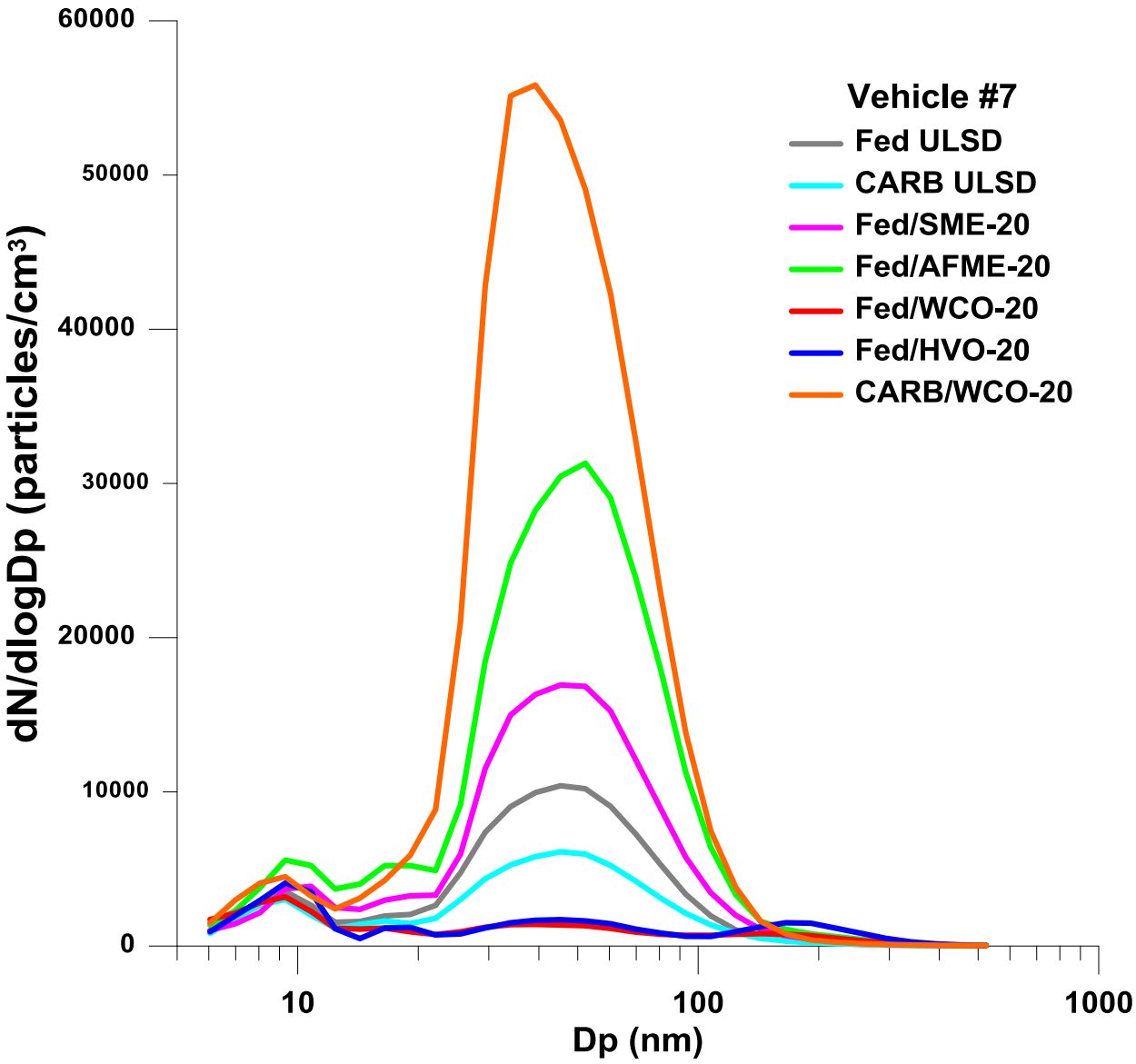


Figure 3-17: Particle size distributions for Vehicle #7 over the FTP

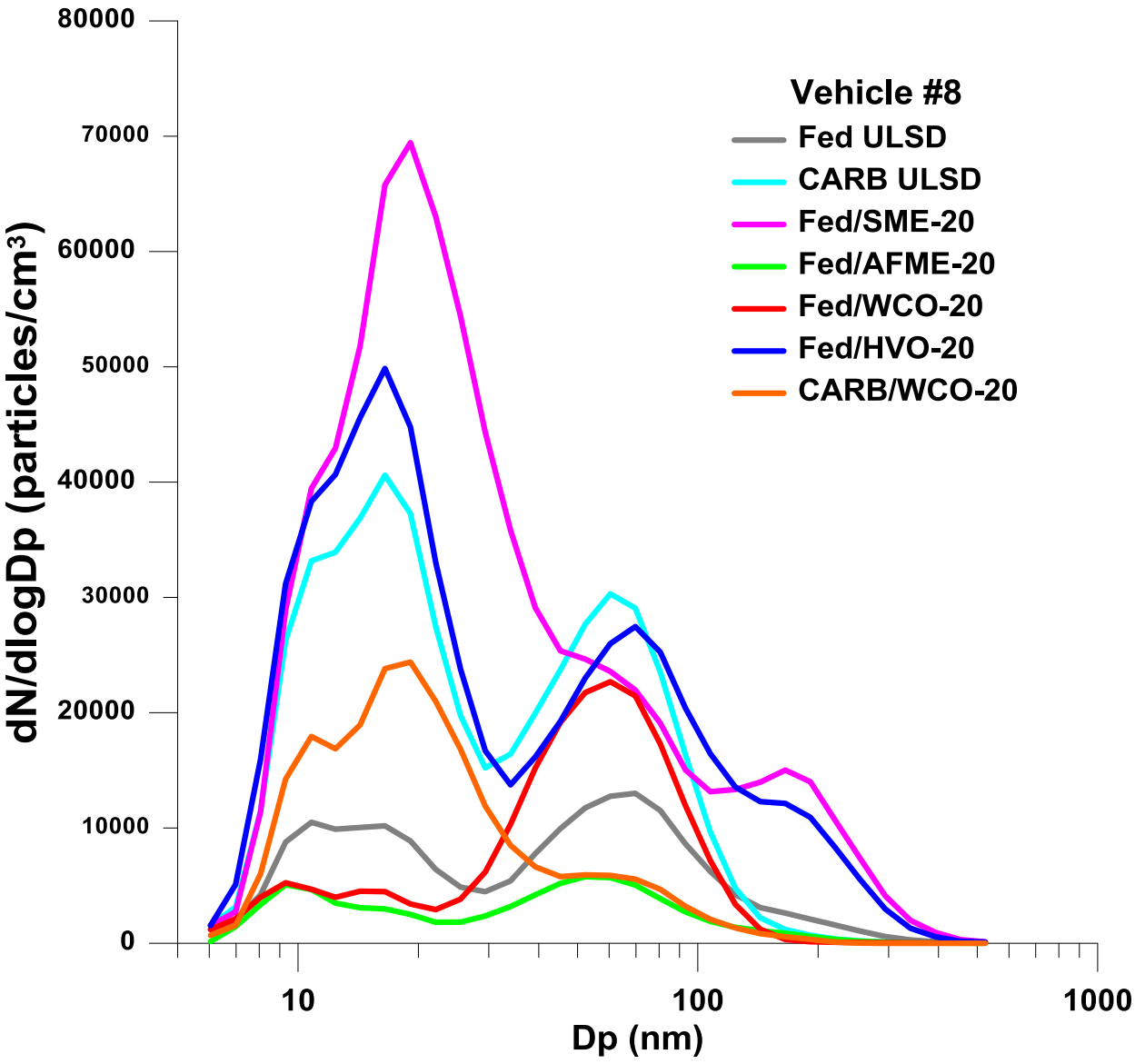


Figure 3-18: Particle size distributions for Vehicle #8 over the FTP

3.8 Carbonyl Emissions

Carbonyl compounds play an important role in atmospheric chemistry and urban air quality because they are precursors to free radicals, ozone, and peroxyacyl nitrates (PAN). Aldehydes such as formaldehyde, acetaldehyde, and acrolein are characterized as motor vehicle air toxics and are known human carcinogens or irritants. Five carbonyl compounds (formaldehyde, acetaldehyde, acrolein, propionaldehyde, and methyl ethyl ketone (MEK)) are listed as hazardous air pollutants (HAP) by the US EPA. Some aldehydes, such as formaldehyde, acetaldehyde, acrolein, and some di-aldehydes also have high incremental reactivity for ozone formation, which may result in increased ground level ozone (a regulated air pollutant) and pose air quality problems for areas that are already in ozone non-attainment or are on the borderline of attainment.

This study identified formaldehyde and acetaldehyde as the predominant aldehyde compounds in the exhaust, with some of the heavier carbonyl compounds either being detected in lesser amounts for some of the test vehicles or below the CVS tunnel background levels for the other vehicles. These results are consistent with those of Fontaras et al. (2010), Karavalakis et al. (2011), Macor et al. (2011), and He et al. (2009), showing the predominance of low molecular-weight carbonyls in emissions from biodiesel-fueled vehicles/engines. These results also indicate that high molecular-weight carbonyl compounds, such as aromatic aldehydes and heavier saturated aliphatic aldehydes, were effectively oxidized in the DOC/DPF system for most test vehicles, suggesting that the vehicle aftertreatment control technology greatly exceeds the fuel effect for heavier carbonyl emission rates. Figures 3.19 and 3.20 show the formaldehyde and acetaldehyde emissions, respectively, for all vehicle/fuel combinations measured over the FTP. There were statistically significant differences in formaldehyde emissions between the test fuels for the vehicle fleet as a whole. More specifically, CARB ULSD showed a statistically significant decrease in formaldehyde emissions of 32% compared to Federal ULSD. Compared to CARB ULSD, the blends of Fed/SME-20, Fed/AFME-20, and Fed/WCO-20 showed statistically significant increases in formaldehyde emissions of 79%, 54%, and 75%, respectively. For acetaldehyde emissions, CARB ULSD showed a statistically significant decrease of 39% compared to Federal ULSD, whereas Fed/SME-20, Fed/WCO-20, and Fed/HVO-20 blends showed statistically significant increases of 79%, 72%, and 60%, respectively, compared to CARB ULSD. A marginally statistically significant increase of 53% for Fed/AFME-20 blend relative to CARB ULSD was also observed. Higher formaldehyde and acetaldehyde emissions with biodiesel fuels compared to petroleum diesels have also seen in previous studies (Fontaras et al., 2010a; Karavalakis et al., 2011b; Macor et al., 2011; Martini et al., 2007). In general, the higher carbonyl emissions for the biodiesel blends could be attributed to the oxygenated ester group. Previous studies have also reported that the use of paraffinic fuels can reduce carbonyl emissions compared to oxygenated fuels such as methyl esters (Heikkila et al., 2012), although this phenomenon has not been observed under the present test conditions.

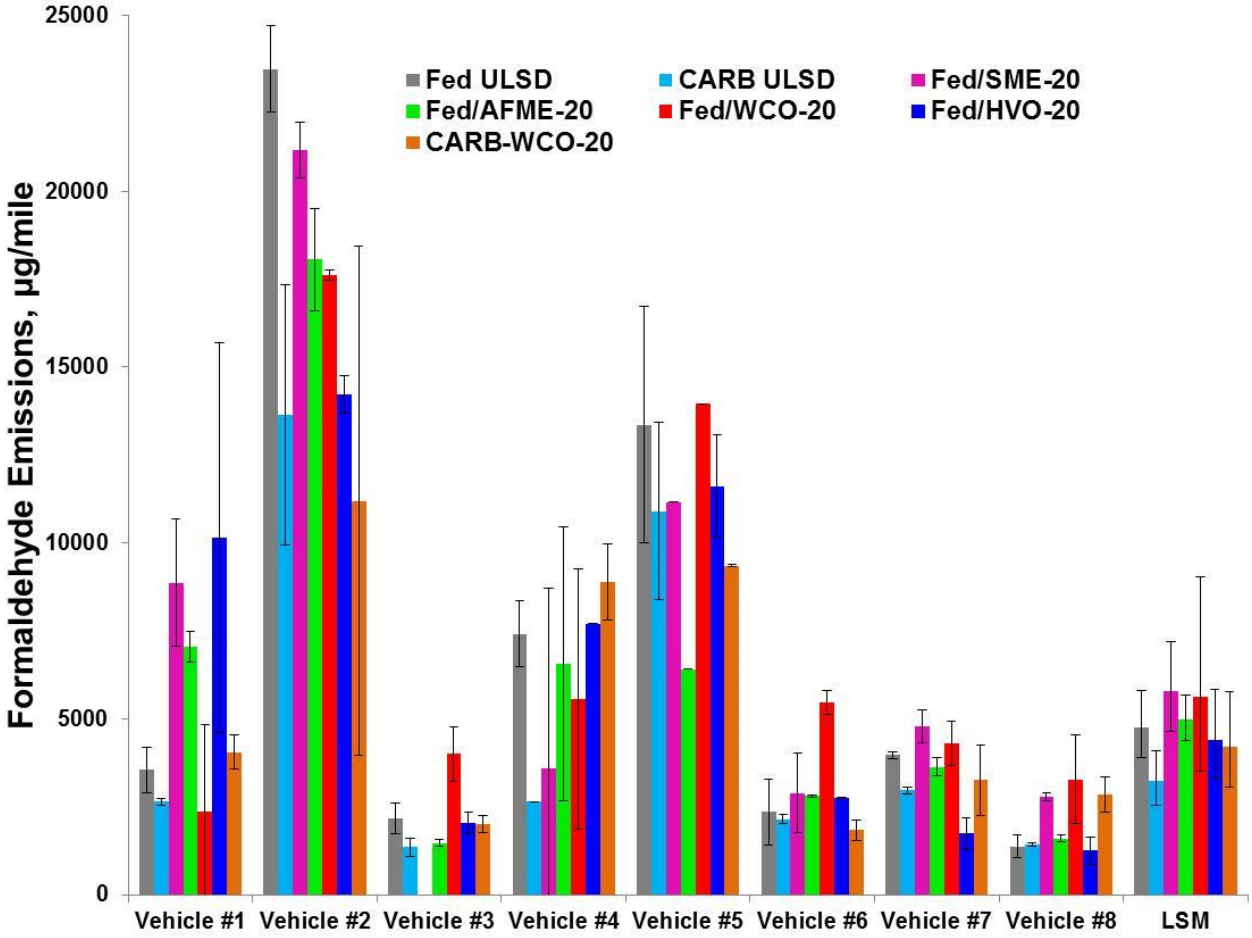


Figure 3-19: Formaldehyde emissions for all vehicle/fuel combination over the FTP

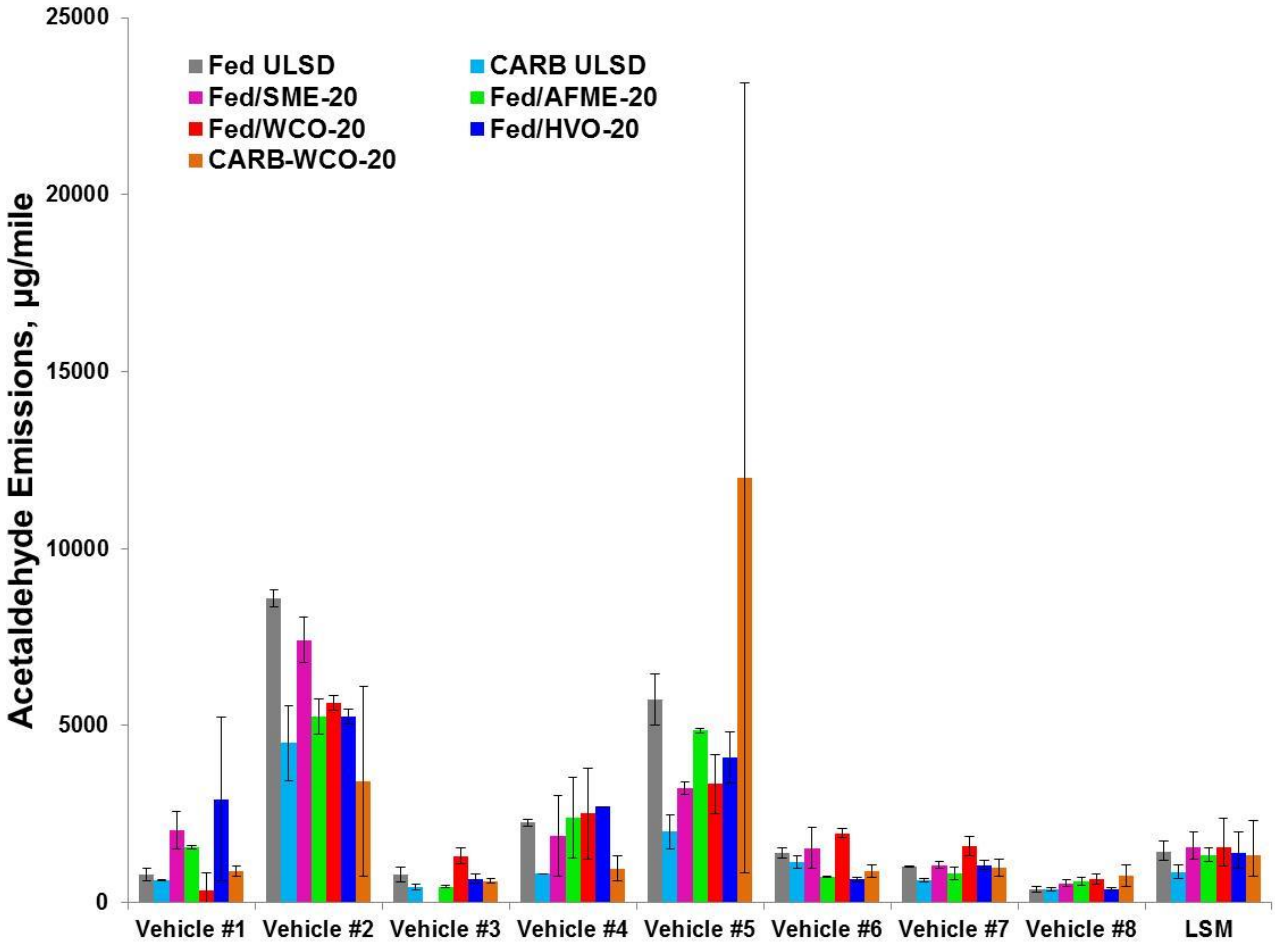
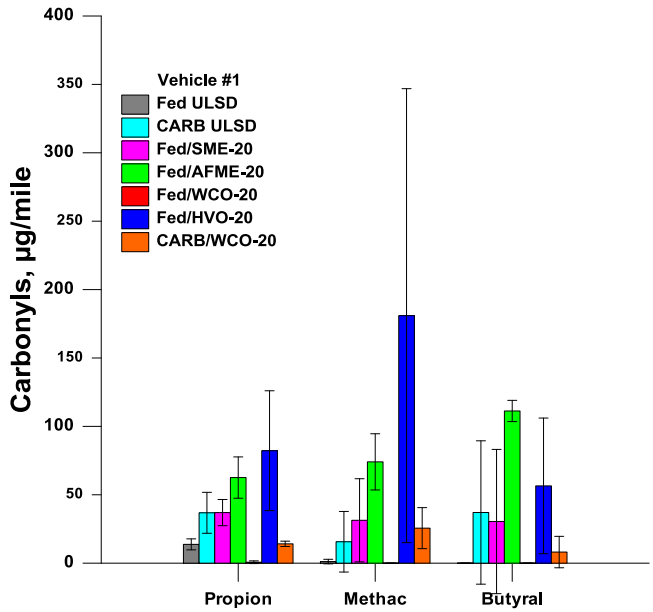
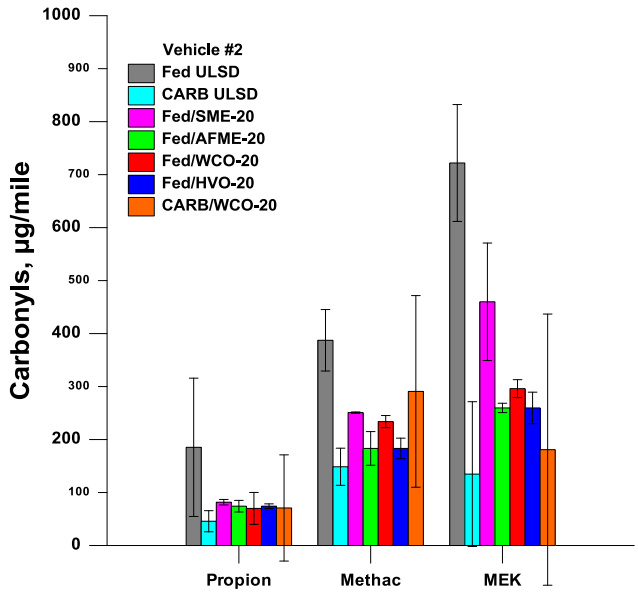
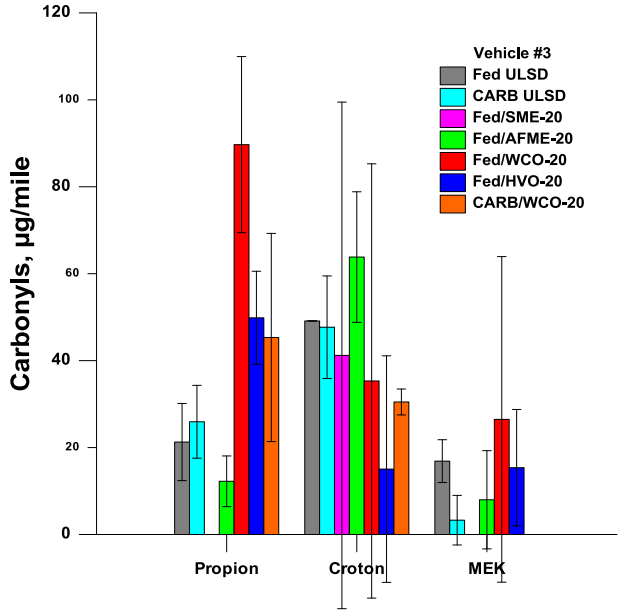


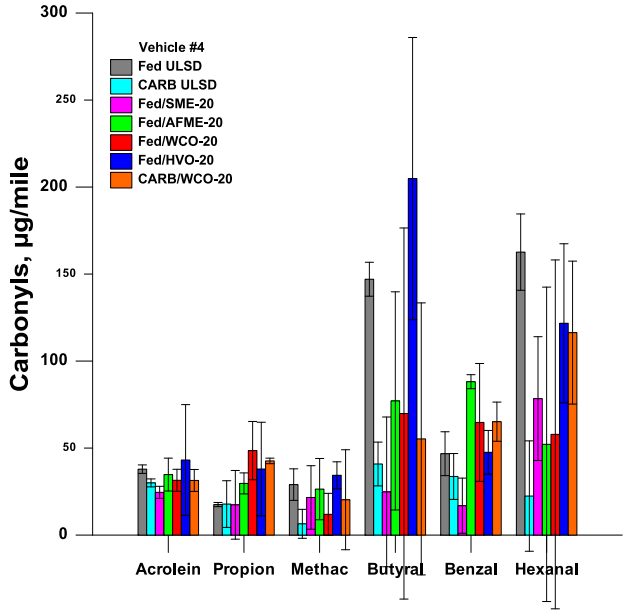
Figure 3-20: Acetaldehyde emissions for all vehicle/fuel combination over the FTP

Figure 3.21 (a-g) shows the main higher molecular weight aldehydes and ketones identified in each vehicle's exhaust. For most of the test vehicles, propionaldehyde, methacrolein, and methyl ethyl ketone (MEK) were the dominant higher molecular weight carbonyls in the exhaust. Data for Vehicle #7 is not included because the majority of heavier aldehydes and ketones were close to or below the CVS background levels. While the concentrations of these compounds were substantially lower compared to those of formaldehyde and acetaldehyde, and characterized by large measurement variability, fuel trends were observed for some vehicles but not for others. For Vehicle #2 and Vehicle #5, for example, the biofuel blends generally showed a decreasing trend in most carbonyl compounds relative to Federal ULSD. There was also a trend for higher higher carbonyl emissions for Fed/AFME-20 for Vehicle #1.


Vehicle #1
Fed ULSD
CARB ULSD
Fed/SME-20
Fed/AFME-20
Fed/WCO-20
Fed/HVO-20
CARB/WCO-20
Carbonyls, µg/mile
0
50
100
150
200
250
300
350
400
Propion
Methac
Butyral


Vehicle #2
Fed ULSD
CARB ULSD
Fed/SME-20
Fed/AFME-20
Fed/WCO-20
Fed/HVO-20
CARB/WCO-20
Carbonyls, µg/mile
0
100
200
300
400
500
600
700
800
900
1000
Propion
Methac
MEK


Vehicle #3
Fed ULSD
CARB ULSD
Fed/SME-20
Fed/AFME-20
Fed/WCO-20
Fed/HVO-20
CARB/WCO-20
Carbonyls, µg/mile
0
20
40
60
80
100
120
Propion
Croton
MEK


Vehicle #4
Fed ULSD
CARB ULSD
Fed/SME-20
Fed/AFME-20
Fed/WCO-20
Fed/HVO-20
CARB/WCO-20
Carbonyls, µg/mile
0
50
100
150
200
250
300
Acrolein
Propion
Methac
Butyral
Benzal
Hexanal

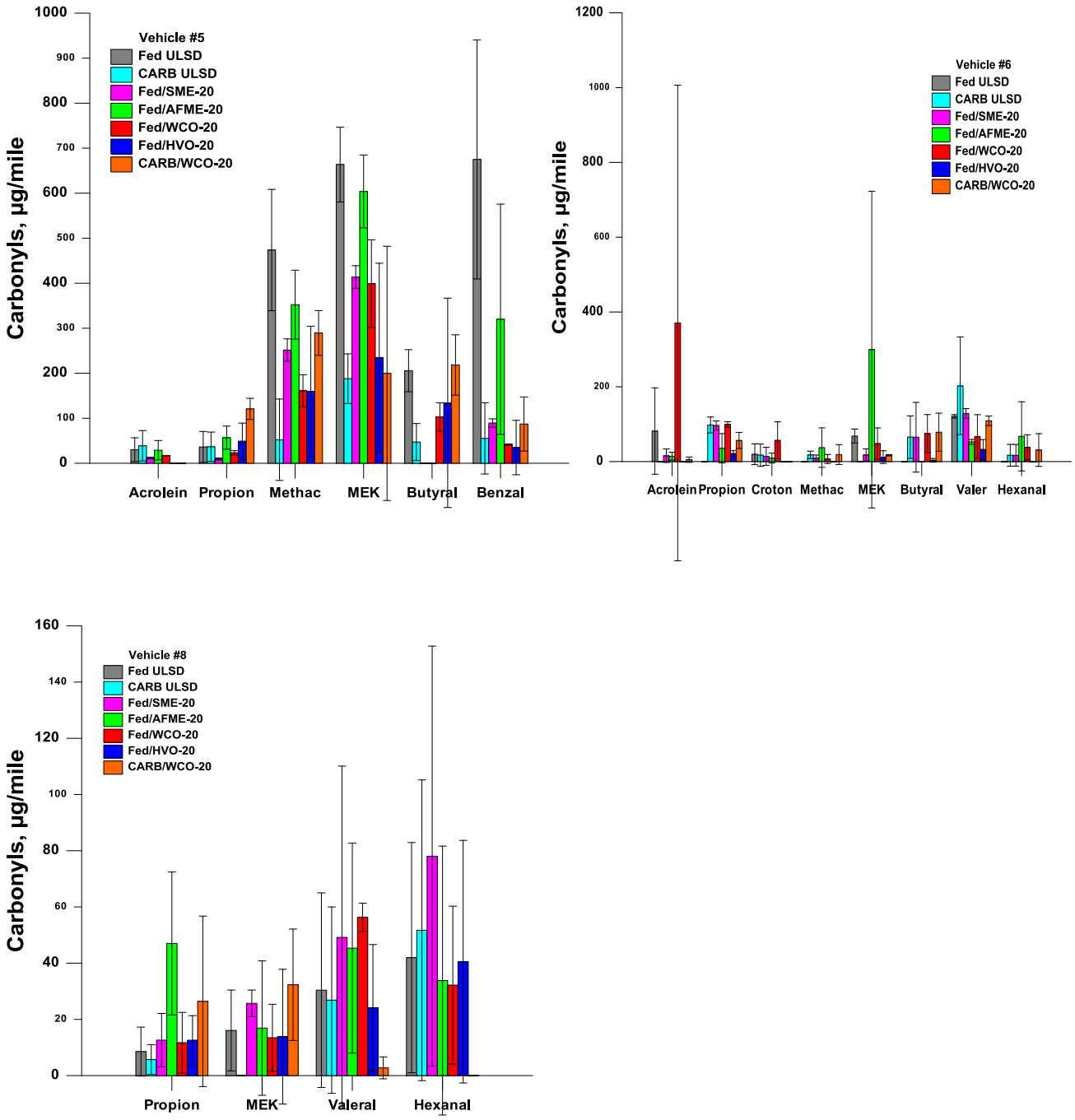


Figure 3-21 (a-g): Higher molecular weight carbonyl compounds for the test vehicles

3.9 PAH and nitro-PAH Emissions

Polycyclic aromatic hydrocarbons (PAHs) are a class of complex organic molecules, which include carbon and hydrogen with a fused ring structure containing at least 2 benzene rings. PAH emissions mainly originate from fuel combustion (pyrosynthesis of aromatic compounds), unburned fuel (pyrolysis of fuel fragments), and unburned lubricating oil. PAH compounds are widely distributed in the atmosphere, and they are well known for their mutagenic and carcinogenic properties. A total of 16 PAHs, ranging in size, from naphthalene (2-rings) to benzo[g,h,i]perylene and indeno[1,2,3-c,d]pyrene (6-rings) have been identified as priority pollutants by the US EPA.

For this program, more than 100 gas- and particle-phase PAH compounds were identified and quantified in the exhaust of each vehicle/fuel combination, including non-substituted PAHs, methyl- and ethyl-substituted PAHs, and oxygenated PAHs. Tables D1 through D16 summarize the PAH emission results (see Appendix D), while Figure 3.22 (a-b) shows the total gas- and particle-phase PAH emissions. In addition, Figures 3.23 (a-b) through 3.25 (a-b) present the total PAH emissions for each vehicle/fuel combination categorized by family compound, including total non-substituted PAHs, total methyl- and ethyl-substituted PAHs, and total oxygenated PAHs.

Overall, the results showed that lower and medium molecular-weight PAHs were the dominant compounds in the exhaust for all vehicle/fuel combinations (see Appendix D). The higher levels of light PAHs suggest that these compounds were pyrolyzed from incomplete combustion of the fuel (Lea-Langton et al., 2008). Previous vehicle and engine studies have also reported the dominant profile of light PAHs in biodiesel exhaust (Martini et al., 2007; Karavalakis et al., 2010b; Karavalakis et al., 2011b; Macor et al., 2011). Some heavier PAHs were also found in the exhaust of all eight vehicles, but in lesser amounts than those of light PAHs. The formation of these species might be due to pyrosynthesis of lower molecular-weight aromatic compounds to larger PAHs and to the contribution of the lubricant oil (Lim McKenzie et al., 2007). Higher molecular-weight compounds, such as those of benzo(b)fluoranthene, benzo(k)fluoranthene, dibenzo(ah)anthracene, dibenzo(a,j)anthracene, benzo(b)chrysene, coronene, dibenzo(a,e)pyrene, dibenzo(a,i)pyrene, dibenzo(a,h)pyrene, dibenzo(ah+ac)anthracene, and dibenzo(b,k)fluoranthene were found to be almost undetectable for most vehicle/fuel combinations. This phenomenon was more pronounced for the gas-phase PAHs, where the majority of medium and heavier PAHs were at very low concentrations or undetectable for most fuels compared to the particle-phase PAHs. Additionally, the results indicated that with increasing ring-number, PAHs were retained more efficiently in the DPF/DOC system.

The results for the biodiesel and the renewable diesel blends did not show clear fuel trends, with both increases and decreases in PAH emissions compared to the reference Federal ULSD and CARB ULSD. For this study, statistical analyses were run on some selected PAH species that were found in relatively high concentrations for all vehicle/fuel combinations. For the particle-phase PAHs, statistical analysis was performed on phenanthrene, 2-methylphenanthrene, 3-methylphenanthrene, fluoranthene, and pyrene. For the gas-phase PAHs, statistical analysis was performed on the predominant naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, fluorene, phenanthrene, fluoranthene, and pyrene. Fluorene was selected because it was a dominant PAH compound for all vehicle/fuel combinations in the gas-phase but not in the particle-phase. Statistical analysis did not show any strong fuel effects for most PAH compounds except for fluorene. For fluorene emissions, the only statistically significant difference was found with Fed/SME-20, which showed a 238% increase compared to CARB ULSD.

Total particle-phase PAH emissions, as shown in Figure 3.22a, revealed that the biodiesel blends and renewable diesel blend led to increases compared to Federal ULSD and CARB ULSD for some vehicles and decreases for some others. The higher total particle-phase PAH emissions for some vehicles/fuel combinations were due to the presence of higher concentrations of light, semi-volatile PAH compounds, including naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, 2,6+2,7-dimethylnaphthalene, 1,4+1,5+2,3-dimethylnaphthalene, and phenanthrene, which were abundant in the particle-phase, as well as in the gas-phase.

Total gas-phase PAH emissions were found in significantly higher concentrations than their corresponded particle-phase PAHs (Figure 3.22b). The highest contributors to the gas-phase PAHs were mainly the two-membered ring compounds and their ethyl- and methyl-substitutes. These were naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, 2,6+2,7-

dimethylnaphthalene, 1,3+1,6+1,7dimethylnaphthalene, acenaphthene, 1+2 ethylnaphthalene, and trimethylnaphthalenes. The next major contributors to the gas-phase PAHs were three-membered ring PAH compounds, including fluorene, phenanthrene, and methylphenanthrenes. It should be noted that some heavier compounds, such as fluoranthene and pyrene, were detected in significantly higher concentrations relative to the particle-phase. These results indicate that fluoranthene, pyrene, and phenanthrene are typical semi-volatile compounds that should be accounted for in both the gas-phase and particle-phase. Heavier molecular-weight PAHs were almost absent in the gas-phase, indicating that these compounds made a negligible contribution to the total gas-phase PAHs. Some exceptions were observed for Vehicle #2, such as indeno[1,2,3-cd]pyrene, which is a six-membered ring compound and a probable human carcinogen. For Vehicle #5, the very high total gas-phase PAH concentration for Federal ULSD was primarily due to the high levels of naphthalene compared to the other fuels. The high levels of naphthalene for Vehicle #5 on the Federal ULSD fuel were found in both tests conducted for that test matrix point.

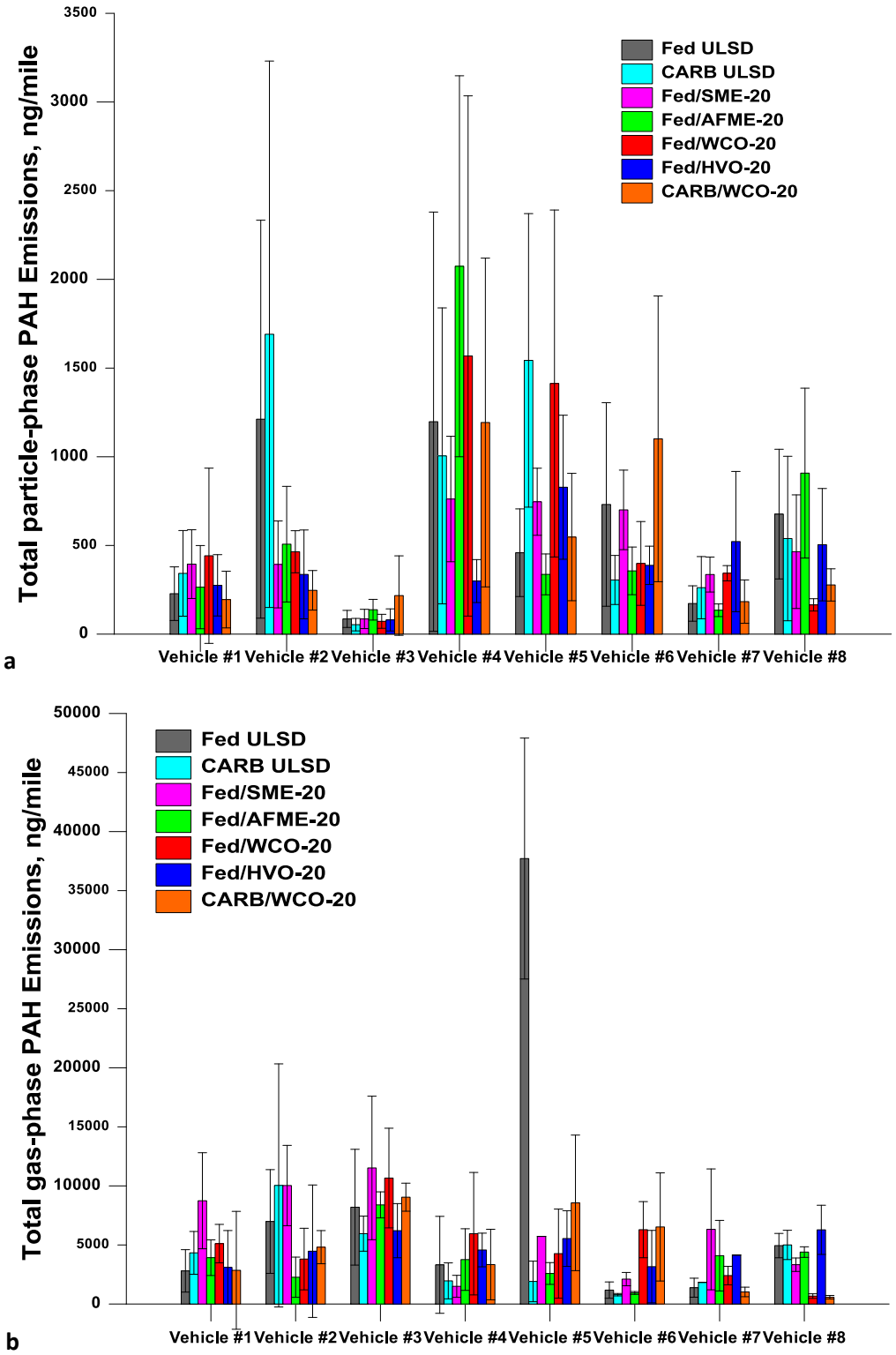


Figure 3-22 (a-b): Total particle-phase (a) and gas-phase (b) PAH emissions for all vehicle/fuel combinations over the FTP

Figure 3.23 (a-b) presents the total gas- and particle-phase non-substitute PAH emissions for all vehicle/fuel combinations. As expected, the emission levels of the total non-substitute PAHs were found to be much lower than those of total PAHs. The emission profile for the particle-phase non-substituted PAHs followed patterns similar to the total particle-phase PAHs for all eight vehicles. Similar results were observed for the total non-substituted gas-phase PAHs, which followed the same trends as the total gas-phase PAHs.

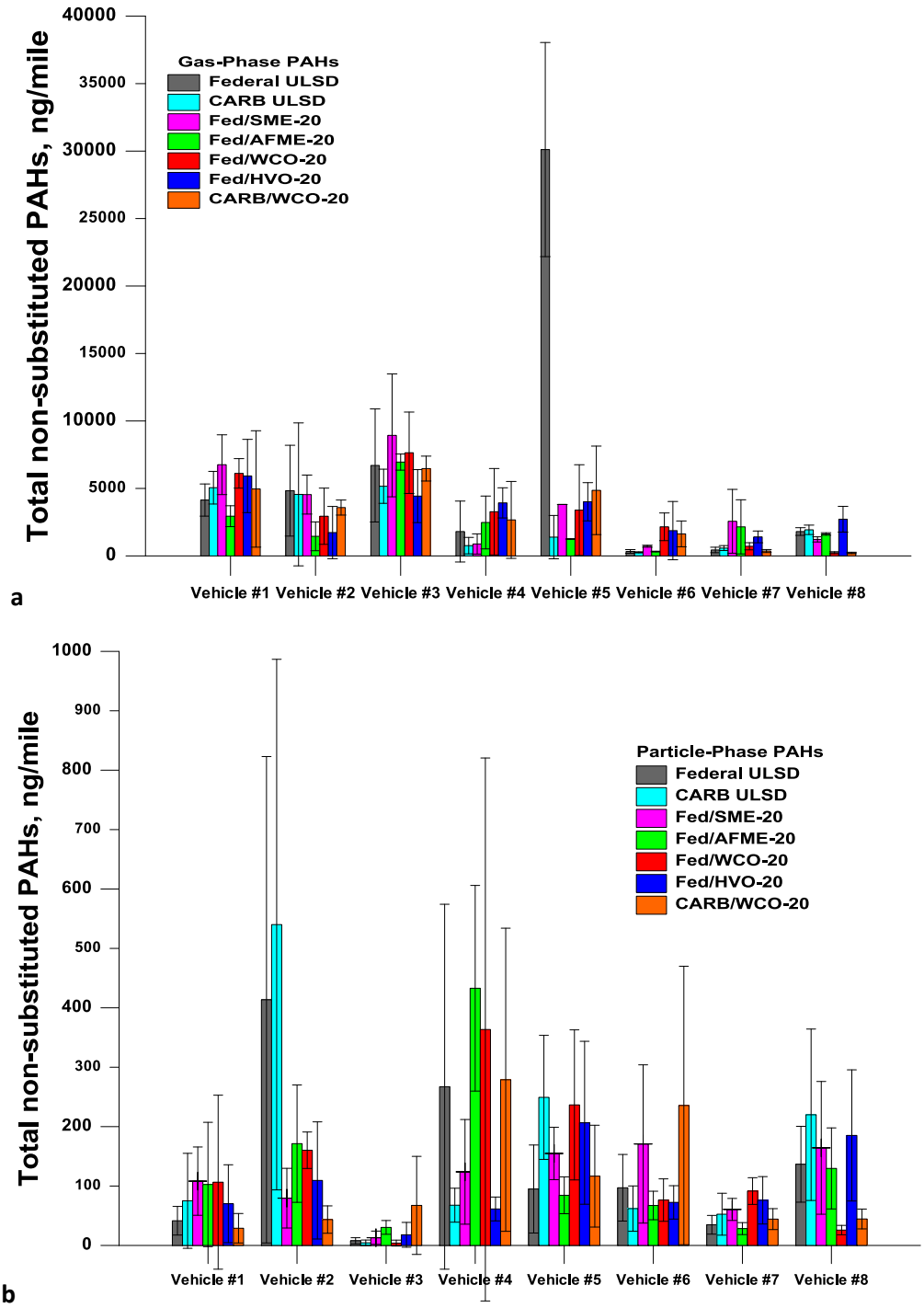
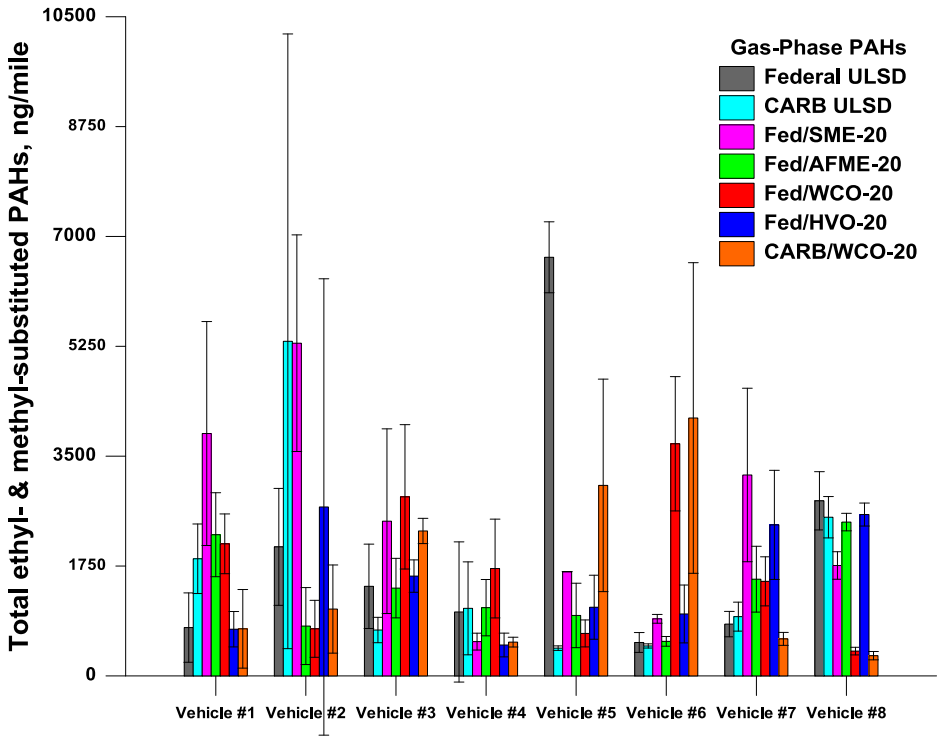
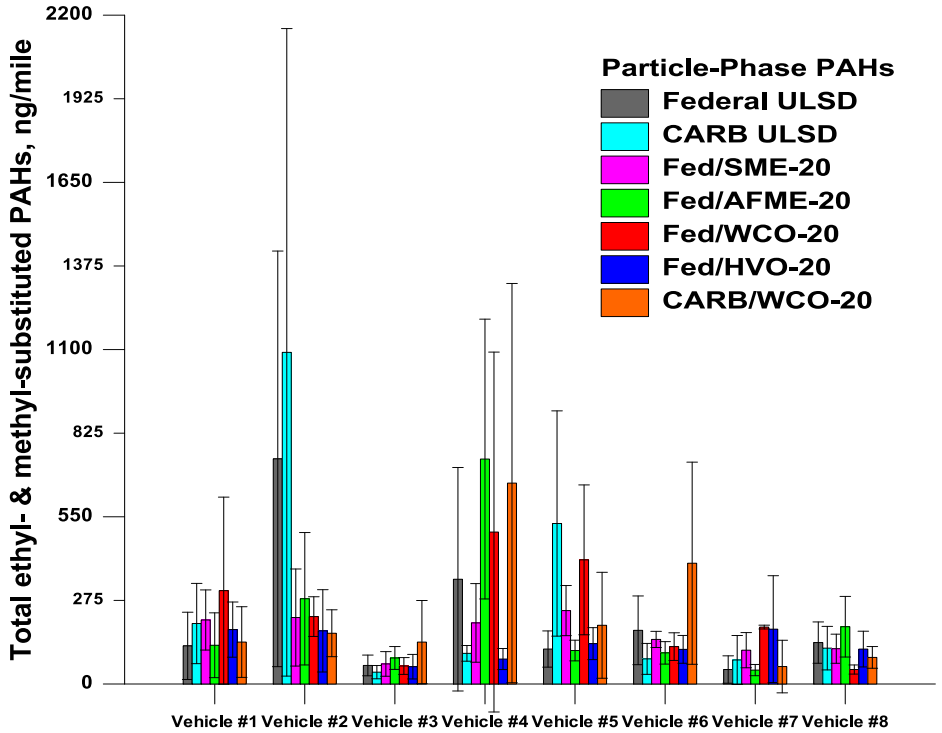


Figure 3-23 (a-b): Total gas- (a) and particle-phase (b) non-substituted PAH emissions for all vehicle/fuel combinations over the FTP

Figure 3.24 (a-b) shows the total gas- and particle-phase ethyl- and methyl-substituted PAH emissions. For the gas-phase total ethyl- and methyl-substituted PAHs, it was observed that the application of the unsaturated soy-based biodiesel blend (Fed/SME-20) led to higher emissions than the Federal ULSD for Vehicle #1, Vehicle #2, Vehicle #3, Vehicle #6, and Vehicle #7. For Vehicle #6, some increases in gas-phase total ethyl- and methyl-substituted PAHs were seen for Fed/WCO-20 and CARB/WCO-20 compared to both ULSD fuels, whereas the opposite phenomenon was observed for Vehicle #8. Particle-phase total ethyl- and methyl-substituted PAH were found in considerably lower concentrations than their corresponded gas-phase components, indicating that both light and heavier ethyl- and methyl-substituted PAHs were either absent from that phase or detected in very low levels.



a



b

Figure 3-24 (a-b): Total gas- (a) and particle-phase (b) ethyl- and methyl-substituted PAH emissions for all vehicle/fuel combinations over the FTP

Oxygenated PAHs (oxy-PAHs) such as polycyclic aromatic quinones have been found to generate reactive oxygen species resulting in oxidative stress that can lead to allergic diseases, and polycyclic aromatic ketones, quinones and anhydrides are well known mutagenic compounds (Knecht et al., 2013). Similar to PAHs, oxy-PAH compounds are emitted mainly from combustion processes, and they can also originate from heterogeneous reactions between PAHs and ozone. In contrast to their parent PAHs, most of the oxy-PAHs found in diesel

particulate matter are directly toxic and mutagenic (Durant et al., 1996). Figure 3.25 (a-b) presents the total gas- and particle-phase oxygenated PAH emissions from all vehicle/fuel combinations. The most abundant oxy-PAH compounds in the exhaust for both phases were xanthone, 9-fluorenone, perinaphthenone, and anthraquinone. The compounds of 1,4-naphthoquinone and anthrone were found at higher concentrations in gas-phase than in particle-phase. Other oxy-PAH compounds, such as 9,10-dihydrobenzo(a)pyrene-7(8H)-one were undetectable for both phases, or found at very low levels, such as those of benz(a)anthracene-7,12-dione, 9-anthraaldehyde, and acenaphthenequinone. It is noteworthy that although acenaphthenequinone was undetectable for the gas-phase, it was found in the particle-phase for some fuels for some vehicles, but not for others. Generally, total oxy-PAH emissions were seen in higher concentrations in the gas-phase than the particle-phase, suggesting that most of these compounds, which were light molecular-weight, three-membered ring PAHs, existed in the gas-phase.

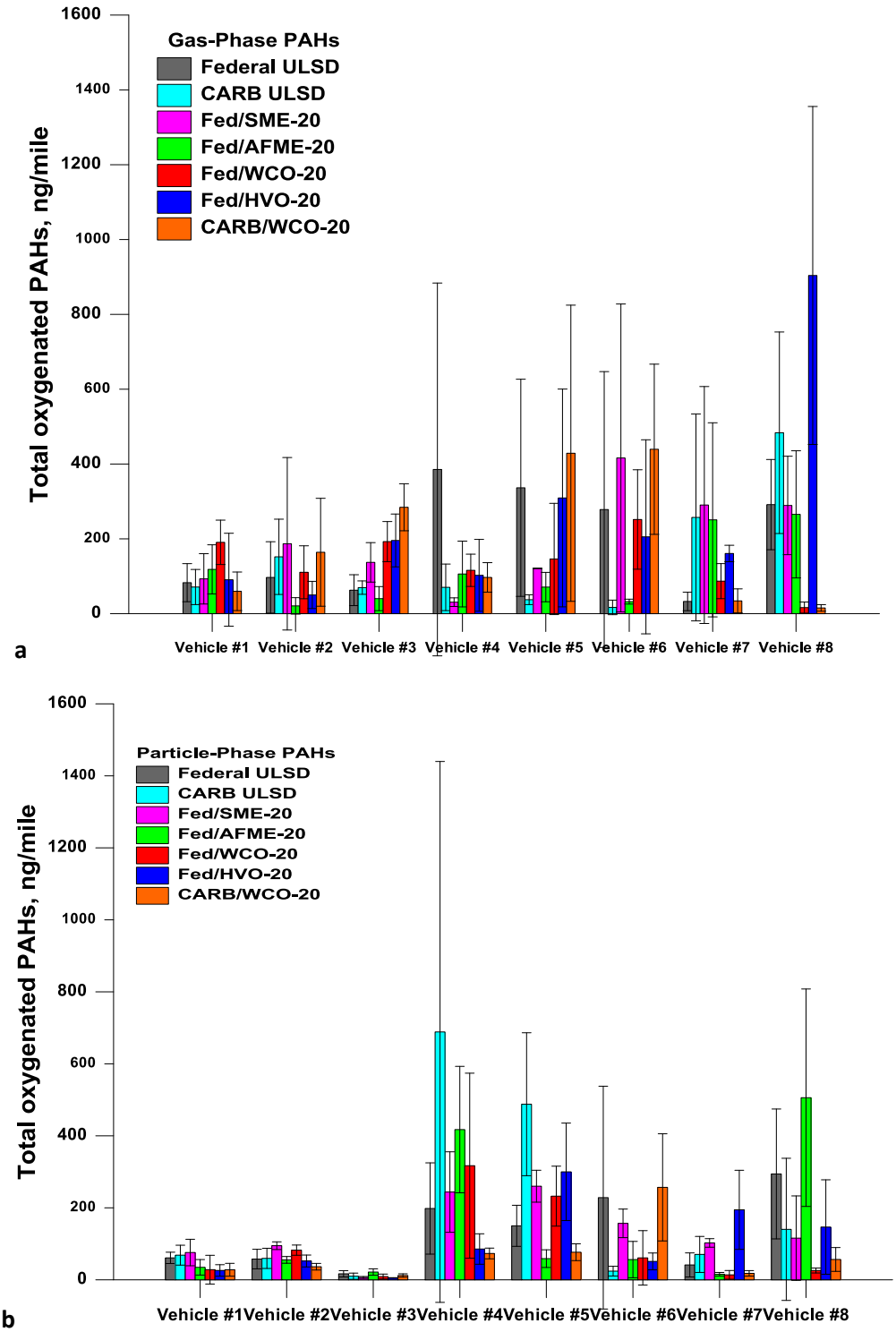


Figure 3-25 (a-b): Total gas- (a) and particle-phase (b) oxygenated PAH emissions for all vehicle/fuel combinations over the FTP

The influence of biodiesel type and source material on individual PAH compounds were not particularly strong. Although some trends were seen for higher emissions for certain light- and heavier PAH species with the use of biodiesel, these phenomena were not consistent throughout the fleet. It is interesting to note that some biodiesel blends showed upward trends in some oxygenated PAH species when compared, specifically, to CARB ULSD. Chrysene, a PAH compound known for its carcinogenic and teratogenic properties, was found at higher concentrations for the soy-based blend (Fed/SME-20) compared to both ULSDs for Vehicle #1, Vehicle #7, and Vehicle #8, and higher than CARB ULSD for Vehicle #4. The concentrations of

7,12-dimethylbenz(a)anthracene, a probable human carcinogen, were also found at relatively higher levels than other heavier particle-phase PAHs for some vehicles, with the unsaturated Fed/SME-20 blend leading to higher emissions of 7,12-dimethylbenz(a)anthracene compared to both ULSDs, but not necessarily to the other biodiesel blends. Higher emissions for the Fed/SME-20 blend compared to the baseline ULSDs were also seen for benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene for almost all vehicles tested. The first two PAH compounds are probable carcinogens, while the latter is considered to be mutagenic and highly carcinogenic. The use of some biodiesel blends also showed some increases in benzo(ghi)perylene for some vehicles, which is toxic and a suspected carcinogen PAH compound. It should be noted that particle-phase benzo(ghi)perylene was found in relative high concentrations among the heavier particle-phase PAH compounds, while it was almost undetectable in the gas-phase. It should also be noted that some methyl-substituted PAHs (methylnapthalenes) found in the gas-phase showed increases for some biodiesel blends when compared to both baseline diesel fuels. It appeared that the soy-based biodiesel blend and the Fed/WCO-20 blend showed some of the most consistent increases in gas-phase methyl-substituted PAH emissions compared to both ULSDs.

The results of this program indicate that the higher PAH levels seen for some biodiesel blends were no doubt due to the combustion process, as there were essentially no aromatics in the biodiesel portion of the unburned fuel blend. Previous studies have shown that the use of unsaturated biodiesel fuels, especially methyl esters obtained from soybean oil, are susceptible to PAH formation and can even led to comparable or higher PAH emissions than regular ULSD (Karavalakis et al. 2010b; Karavalakis et al., 2011a; Ratcliff et al., 2010). Unsaturated compounds react thermally, above 250 – 300 ºC, via the Diels-Alder reaction to dimerize or trimerize to form six-member rings (cyclohexanes). The dehydrogenation of these cyclohexanes produces single ring aromatic compounds, which react further, leading to PAH formation. Alternatively, gaseous olefinic fragments (e.g., acetylene, propargyl, and 1,3-butadiene) from pyrolysis of unsaturated methyl esters may react further to form aromatics. Therefore, it seems reasonable to speculate that pyrolysis of the unsaturated soy-based blend occurring within the diffusion flame of the diesel engine may have produced these aromatic structures. In the case of the renewable diesel blend, the lower or small differentiations in both total gas- and particle-phase PAH emissions could be a consequence of the absence of aromatics compounds in the HVO fuel compared to both reference ULSDs.

Nitrated polycyclic aromatic hydrocarbons (nitro-PAHs) can be either directly produced from combustion sources by electrophilic aromatic substitution reactions between nitrating agents, such as nitrogen dioxide (NO_2), and the parent PAHs, or formed from their parent PAHs by atmospheric OH or NO_3 radical initiated reactions (Miet et al., 2009). Nitration of PAHs also occurs during the catalytic reactions of the exhaust gas in the DPF, and during sampling and cleanup. The latter two would be considered as unwanted artifacts. In the DPF, PAH nitration reactions with NO_2, nitrous acid (HNO_2), and nitric acid (HNO_3) can occur as declining temperatures lead to aerosol formation and adsorption onto PM (Heeb et al., 2008). Most studies have reported that emissions of nitro-PAH compounds from diesel engines/vehicles are typically at least an order of magnitude lower than rates for PAH emissions (Bagley et al., 1998; Ratcliff et al., 2010; Karavalakis et al., 2011b; Hu et al., 2013). However, many nitro-PAHs are highly mutagenic, genotoxic, and carcinogenic (Durant et al., 1996). A total of thirty six nitro-PAH compounds in both gas- and particle-phase were analyzed from 1-nitronaphthalene through 3-nitrobenzo[e]pyrene. Gas-phase and particle-phase nitro-PAH values for all vehicle/fuel combinations along with their standard deviations are presented in Table D17 through Table D32 (see Appendix D). Figures 3.26 and 3.27 show the total gas- and particle-phase nitro-PAH emissions, expressed in ng/mile, for all vehicle/fuel combinations.

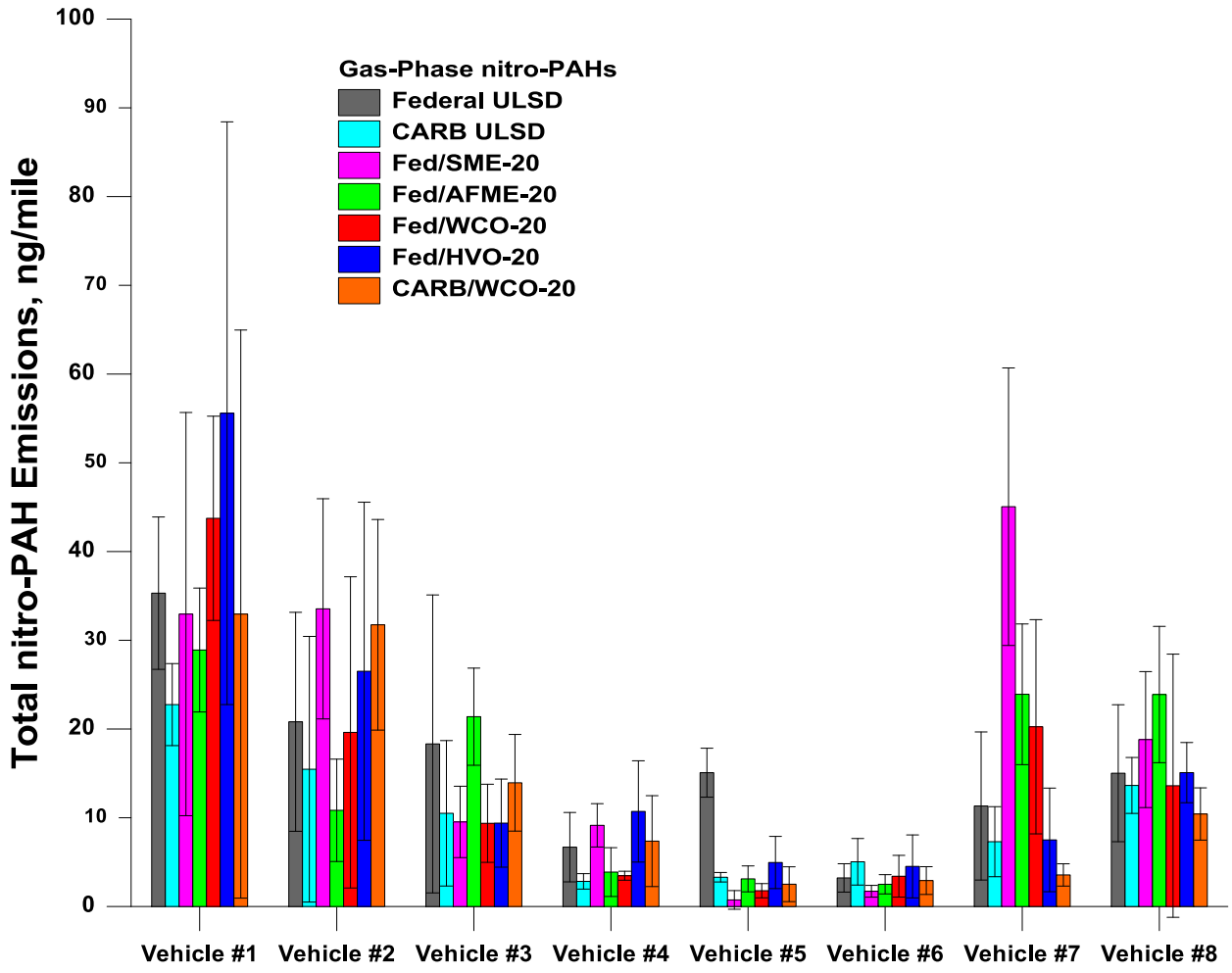


Figure 3-26: Total gas-phase nitro-PAH emissions for all vehicle/fuel combinations over the FTP

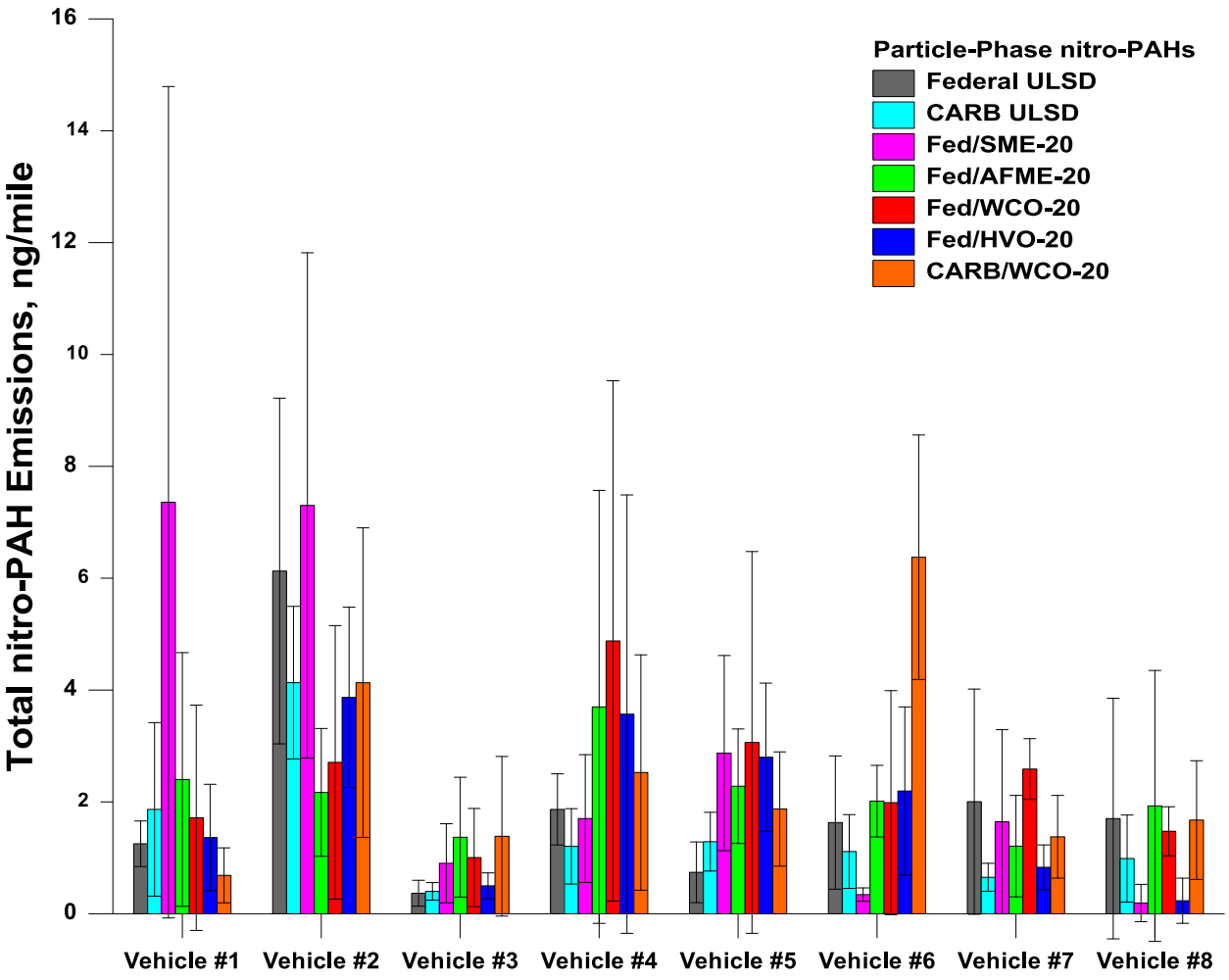


Figure 3-27: Total particle-phase nitro-PAH emissions for all vehicle/fuel combinations over the FTP

The results show that the gas-phase nitro-PAHs are more abundant than particle-phase nitro-PAHs, with light weight molecular compounds, such as 1-nitronaphthalene and methyl-substituted nitronaphthalenes, being dominant in the exhaust. Specifically, the predominant species in the gas-phase for all eight vehicles were 1-nitronaphthalene, 2-nitronaphthalene, 1-methyl-5-nitronaphthalene, 2-methyl-4-nitronaphthalene, 1-methyl-4-nitronaphthalene, 1-methyl-6-nitronaphthalene, 9-nitroanthracene, 1,3-dinitronaphthalene, 9-nitrophenanthrene, and 3-nitrophenanthrene. Higher molecular-weight nitro-PAHs, such as dinitropyrenes, 7-nitrobenz(a)anthracene, and 1-nitrobenzo[e]pyrene, were below the detection limit of the method. In addition to the above species, 1-nitropyrene, a compound that usually partitions exclusively in the particle-phase, was detected in the gas-phase for Vehicle #4, Vehicle #5, Vehicle #6 and Vehicle #7, but not for the other test vehicles. The relatively high concentrations of 3-nitrophenanthrene that were observed for Vehicle #1, Vehicle #2, and Vehicle#3 could be attributed to the selective nitration of phenanthene.

The most abundant nitro-PAH compounds in the particle-phase were 1,3-dinitronaphthalene, 1,8-dinitronaphthalene, 9-nitrophenanthrene, 3-nitrophenanthrene, 1-nitropyrene, 1,6-dinitropyrene, and 4-nitrobiphenyl. Light molecular weight nitro-PAHs, including 1-nitronaphthalene, 2-nitronaphthalene, and 9-nitroanthracene, were also found in the exhaust, which indicates that these compounds partitioned in both the vapor and particle phases. The 1-nitropyrene has been used as marker of diesel exhaust and it is a precursor for 1,3-, 1,6- and 1,8-dinitropyrenes. However, the dinitropyrenes were not detected for most of the test vehicles in this program, with

the exception of 1,6-dinitropyrene, which was present for Vehicle #6 and Vehicle #7. Analogous to the gas-phase nitro-PAHs, heavier particle-phase nitro-PAH species were found to be below the detection limits.

The use of biodiesel blends and the renewable diesel blend produced discordant results for gas- and particle-phase nitro-PAH emissions, with both increases and decreases. Comparing the reference ULSDs, the CARB ULSD showed a trend towards lower total gas- and particle-phase nitro-PAH emissions compared to Federal ULSD. For this study, statistical analysis was performed on some selected nitro-PAH species that were found in relatively high concentrations for all vehicle/fuel combinations. For the gas-phase, statistical analysis was run on 1-nitronaphthalene, 2-nitronaphthalene, and 2-methyl-4-nitronaphthalene. For the particle-phase, statistical analysis was run on 1,3-dinitronaphthalene and 1-nitropyrene. Statistical analysis did not show any strong fuel effects for most nitro-PAH compounds except for the gas-phase 1-nitronaphthalene. For 1-nitronaphthalene emissions, CARB ULSD and CARB/WCO-20 blend showed marginally statistically significant decreases of 87% and 89%, respectively, compared to Federal ULSD.

3.10 Organic and Elemental Carbon Emissions

Organic carbon (OC) emissions are shown in Figure 3.28 for the main FTP portion of the testing program. Although elemental carbon (EC) emissions were also measured for these tests, the EC emissions were near zero for the FTP testing, so the EC results are not included in the figure. The observation that the carbonaceous portion of the PM contains very little EC is consistent with other studies of vehicles equipped with DPFs. Cheung et al. (2009) tested diesel passenger cars with different exhaust configurations, including a DOC and DPF on regular ULSD and on soy-based biodiesel over the NEDC and the Artemis cycles. They found that a DPF-fitted vehicle significantly reduced EC/OC emissions, while a biodiesel-fueled vehicle emitted predominantly OC emissions. Similar trends were reported from Kooter et al. (2011), showing approximately a 90% reduction in the EC fraction of pure biodiesel compared to regular ULSD. They also reported that with the application of a DPF, EC fraction was near zero compared to regular ULSD. The results reported here for the OC emissions did not show any statistically significant fuel effects for the vehicle fleet as a whole.

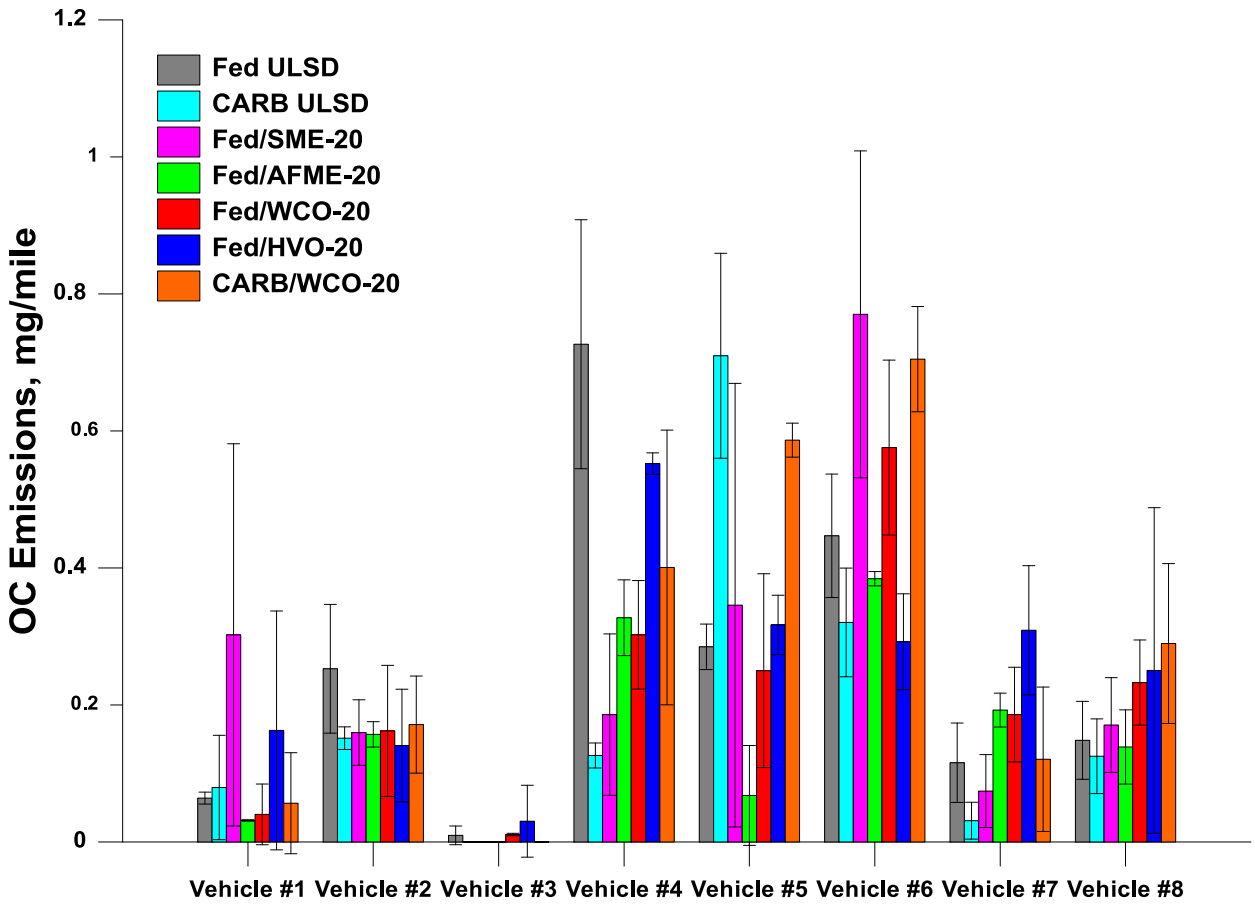


Figure 3-28: Organic Carbon (OC) emissions over the FTP

3.11 Ammonia Emissions

Ammonia (NH_3) emissions for the test vehicles are provided in Figure 3.29. Measureable NH_3 emissions were predominantly seen for Vehicle #1, which had average emissions ranging from 5.5 to 17.5 mg/mi, and Vehicle #2, which had average emissions ranging from 5.1 to 7.8 mg/mi. The NH_3 measurement variability for Vehicle #1 appeared to be due to operational differences from test to test with respect to the SCR system. Specifically, in some tests NH_3 emissions were readily apparent and showed distinct trends, as shown below, while for other tests the NH_3 emissions were near the background levels. Vehicle #3 showed lower, but generally measureable NH_3 emissions ranging from 0.9 to 2.5 mg/mi. The NH_3 emissions for Vehicles #4 through #8 were near the background levels for most of the test matrix points; their average NH_3 emissions were less than 1 mg/mi. Overall, there were no consistent trends in NH_3 emissions between the reference ULSDs and the biodiesel fuels for the fleet of eight vehicles. NH_3 spikes were observed for a few tests even for vehicles where the NH_3 emissions were near zero, namely for Vehicle #5 with the Fed/AFME-20, Vehicle #7 with the Fed/SME-20, and Vehicle #8 with the Fed/SME-20. These spikes appear to be isolated instances of NH_3 slip, predominantly in bag 3, as opposed to actual fuel effects. It should be noted that data are not available for some test matrix points for Vehicle #4 and Vehicle #5, and one point for Vehicle #6, but it is assumed that these data points would be similarly near the background levels for these vehicles.

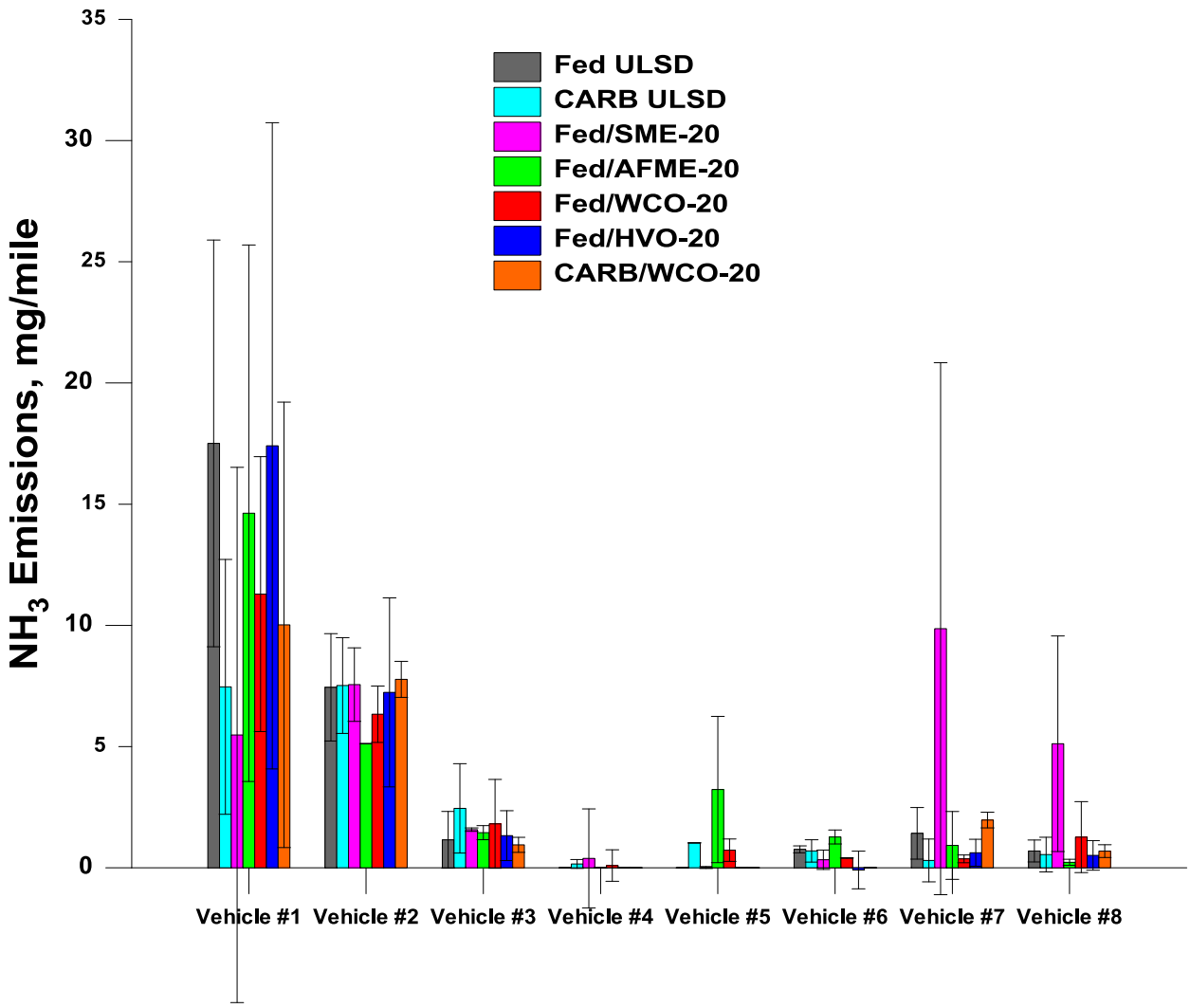


Figure 3-29: NH_3 emissions over the FTP

The real-time traces of NH_3 versus NO_x emissions over the FTP cycle give some insight into their formation mechanisms. For comparison purposes, real-time NH_3 versus NO_x emissions are provided for two fuels, namely Federal ULSD and Fed/WCO-20 blend, on Vehicles #1 and #2, which showed the greatest NH_3 emissions. These fuels were selected as representative of the fuels tested during the course of this program. Figure 3.30 (a-b) through Figure 3.31 (a-b) presents the real-time NH_3 versus NO_x emissions, expressed in ppm, over the FTP cycle for Vehicle #1 and Vehicle #2. It is clear that for Vehicle #1, NO_x concentrations were highest during the cold-start, with almost negligible NH_3 concentrations at the same time. A substantial reduction in NO_x emissions was seen after approximately the first 300 seconds of the cycle, along with a subsequent increase in NH_3 emissions. This phenomenon was observed for both the Federal ULSD and the biodiesel blend. While the tests shown in the real-time plots for Vehicle #1 showed higher levels of NH_3, there were also tests for Vehicle #1 where the NH_3 emissions were near the background level, as noted above. For Vehicle #2, elevated NO_x emissions were also seen for both fuels during the cold-start phase of the FTP, with NO_x emissions declining significantly after the first 300 seconds of the cycle. Emissions of NH_3 for Vehicle #2, however, were at very low concentrations throughout the entire cycle, and were very close to the background level.

The functioning of an SCR depends on the catalyst material, urea dosing strategy, temperature, and physical system layout. A certain minimum exhaust temperature is required for SCR to promote hydrolysis of urea into NH_3, which then reduces NO_x into elemental nitrogen (N_2) and water (H_2O). As a result, SCR function depends on driving conditions to the extent that they affect exhaust temperature and urea dosing strategy. Under the present test conditions, the higher NO_x emissions under cold-start could be attributed to the insufficient exhaust temperature for urea hydrolysis and optimum catalyst activity, as the SCR catalyst was below its light-off temperature. During phase 2 and phase 3 of the FTP, NO_x emissions were reduced to very low concentrations, showing that SCR was effective in controlling NO_x when the exhaust temperatures were sufficiently high. Other chassis dynamometer studies have also reported elevated NO_x emissions during cold-starts, with the bulk of these studies being carried out in heavy-duty diesel vehicles equipped with SCR control technology (Williams et al., 2010; Misra et al., 2013).

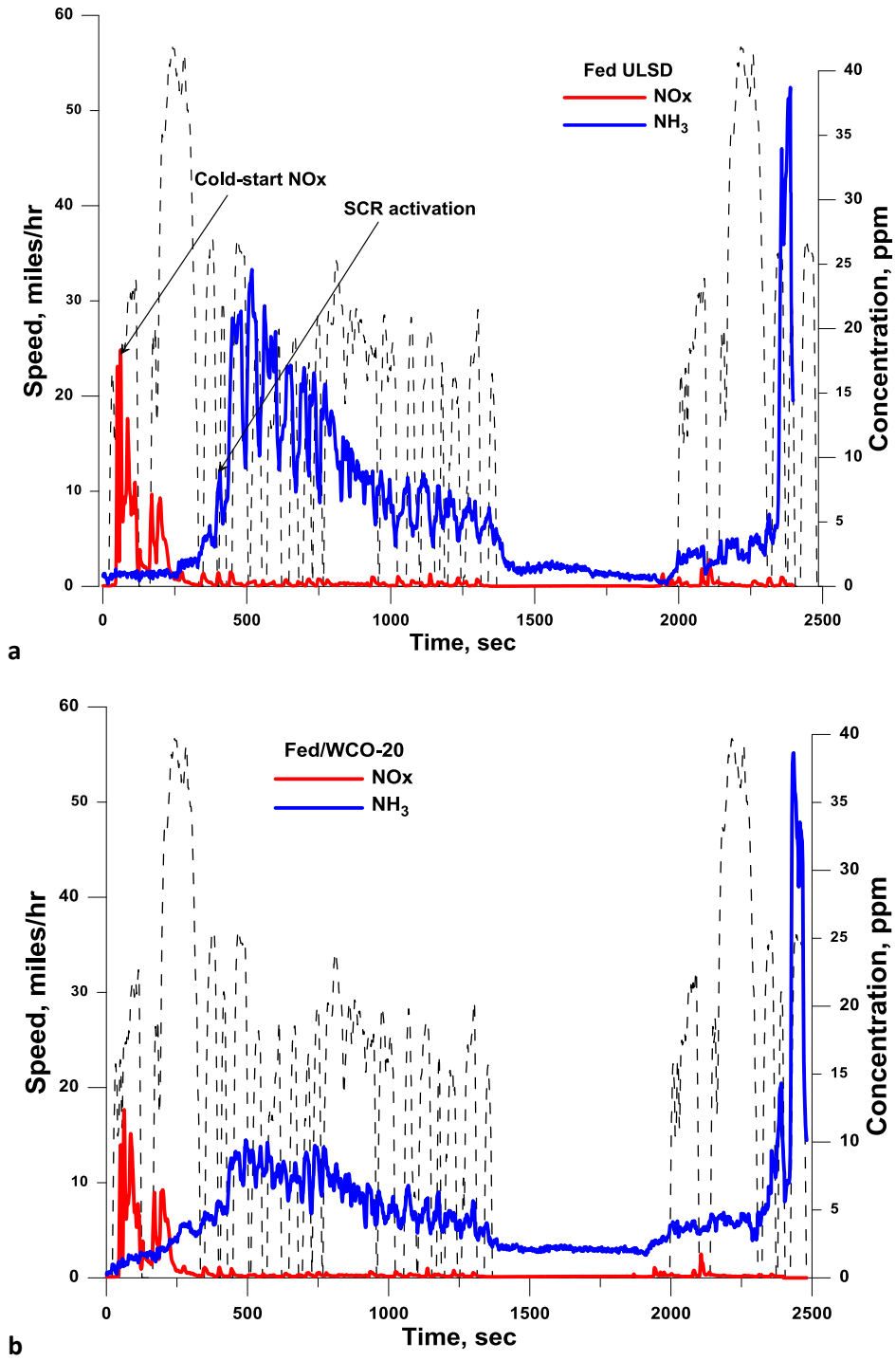


Figure 3-30 (a-b): Real-time NH_3 versus NO_x emissions for Federal ULSD (a) and Fed/WCO-20 blend (b) over the FTP for Vehicle #1

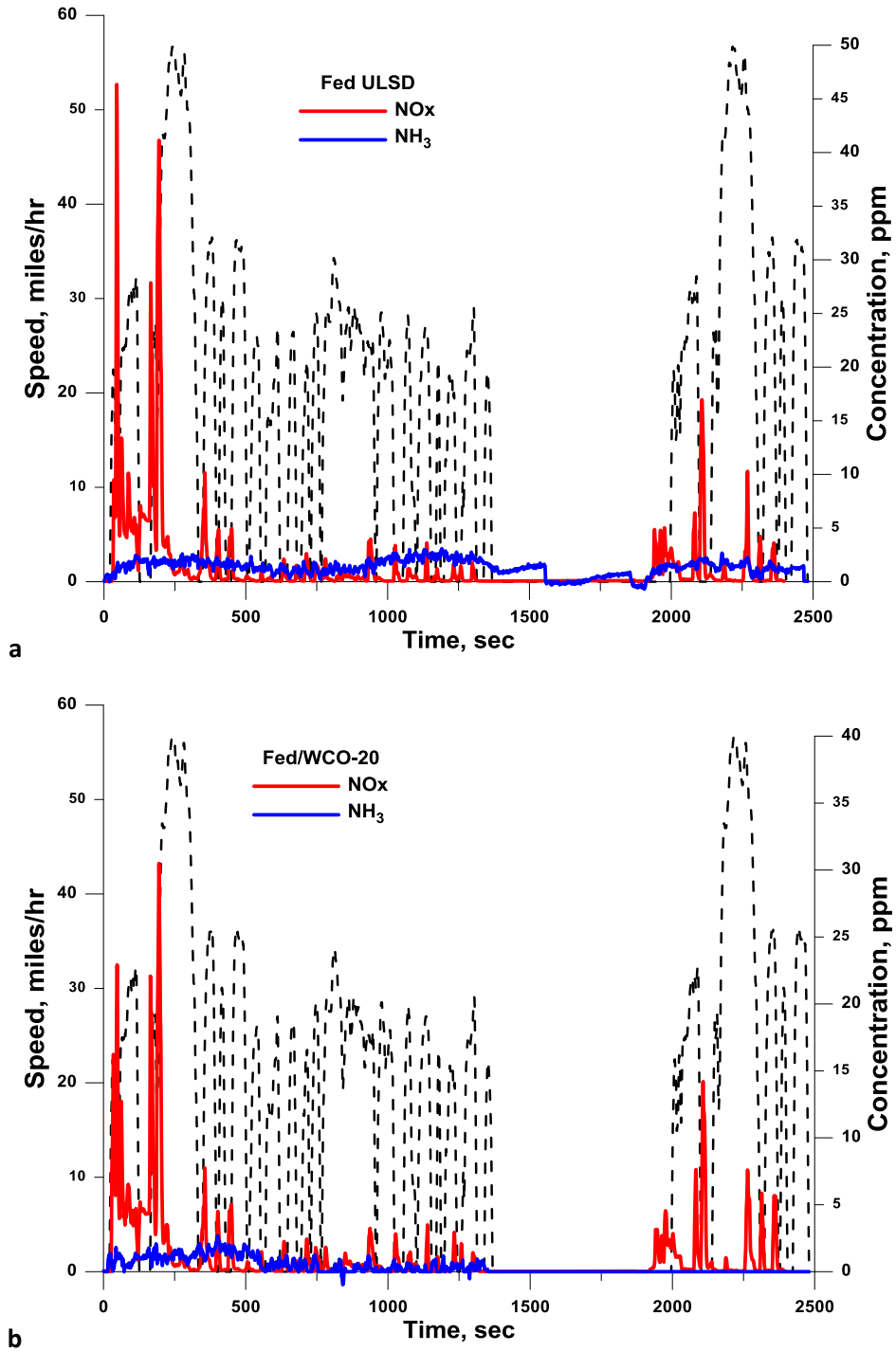


Figure 3-31 (a-b): Real-time NH_3 versus NO_x emissions for Federal ULSD (a) and Fed/WCO-20 blend (b) over the FTP for Vehicle #2

3.12 Nitrogenous Compounds

Nitrogenous compounds, including nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O), were only measured during the second phase of the AVFL-17b program and limited to Vehicle #4 through Vehicle #8. NO, NO_2, and N_2O emissions, as well as the NO:NO_2 ratio are shown in Figures 3.32, 3.33, 3.34, and 3.35, respectively. For NO emissions, no statistically significant fuel effects were seen for the five vehicles tested. The light-duty diesel trucks, Vehicle #5 and Vehicle #6, generally showed higher NO emissions than the other test vehicles, and their NO levels followed a trend similar to their NO_x emission levels. NO_2 is a highly

reactive gas contributing to the formation of ground-level ozone and fine particle pollution, and is linked to adverse health effects. NO_2 emissions were higher than those of NO for Vehicle #4, Vehicle #7, and Vehicle #8, as seen in Figure 3.31 and in comparing Figure 3.30 and Figure 3.31. Similar to NO, NO_2 emissions did not show statistically significant fuel effects for the five vehicles tested. However, some trends towards lower NO_2 emissions for the biofuel blends were seen for Vehicle #6 and Vehicle #7. There were also no statistically significant fuel effects for the NO:NO_2 ratio.

N_2O is considered an important GHG emission component, as it is considerably more potent than CO_2. N_2O emissions varied from 0.01 to 0.02 g/mile for Vehicle #4 and Vehicle #6 through Vehicle #8, while Vehicle #5 showed higher N_2O emissions ranging from 0.03 to 0.07 g/mile. N_2O emissions did not show consistent fuel trends over Vehicle #4 through Vehicle #8. This observation is also supported by the statistical analyses, which showed a lack of significant effects among the test fuels. Lower N_2O emissons were found for the Fed/SME-20 and Fed/AFME-20 fuels for Vehicle #5. The Fed/HVO-20 showed higher emissions for Vehicle #7 and lower emissions for Vehicle #8. Vehicle #6 showed higher emissions for Federal ULSD compared to the other fuels.

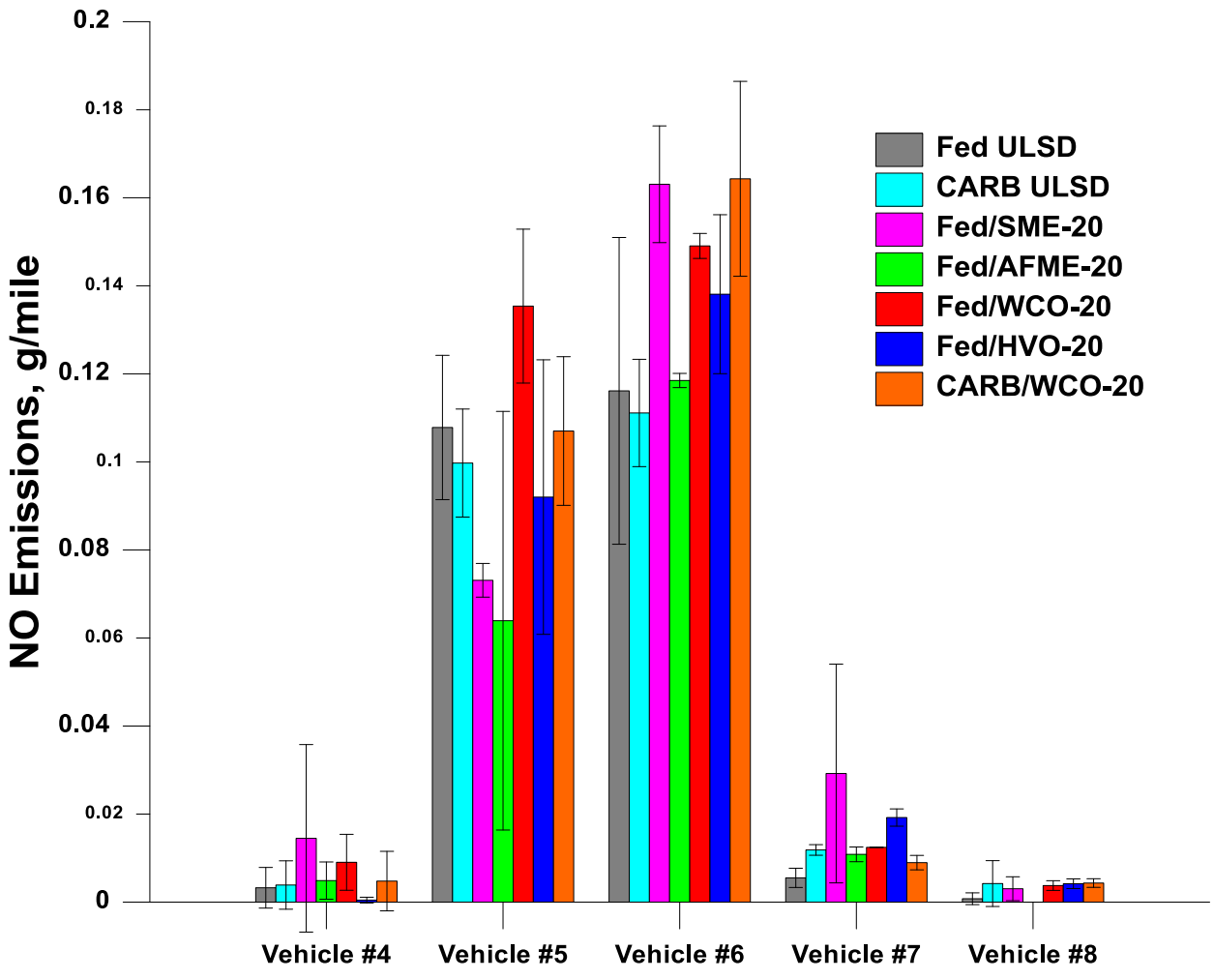


Figure 3-32: NO emissions for Vehicle #4-Vehicle #8 over the FTP

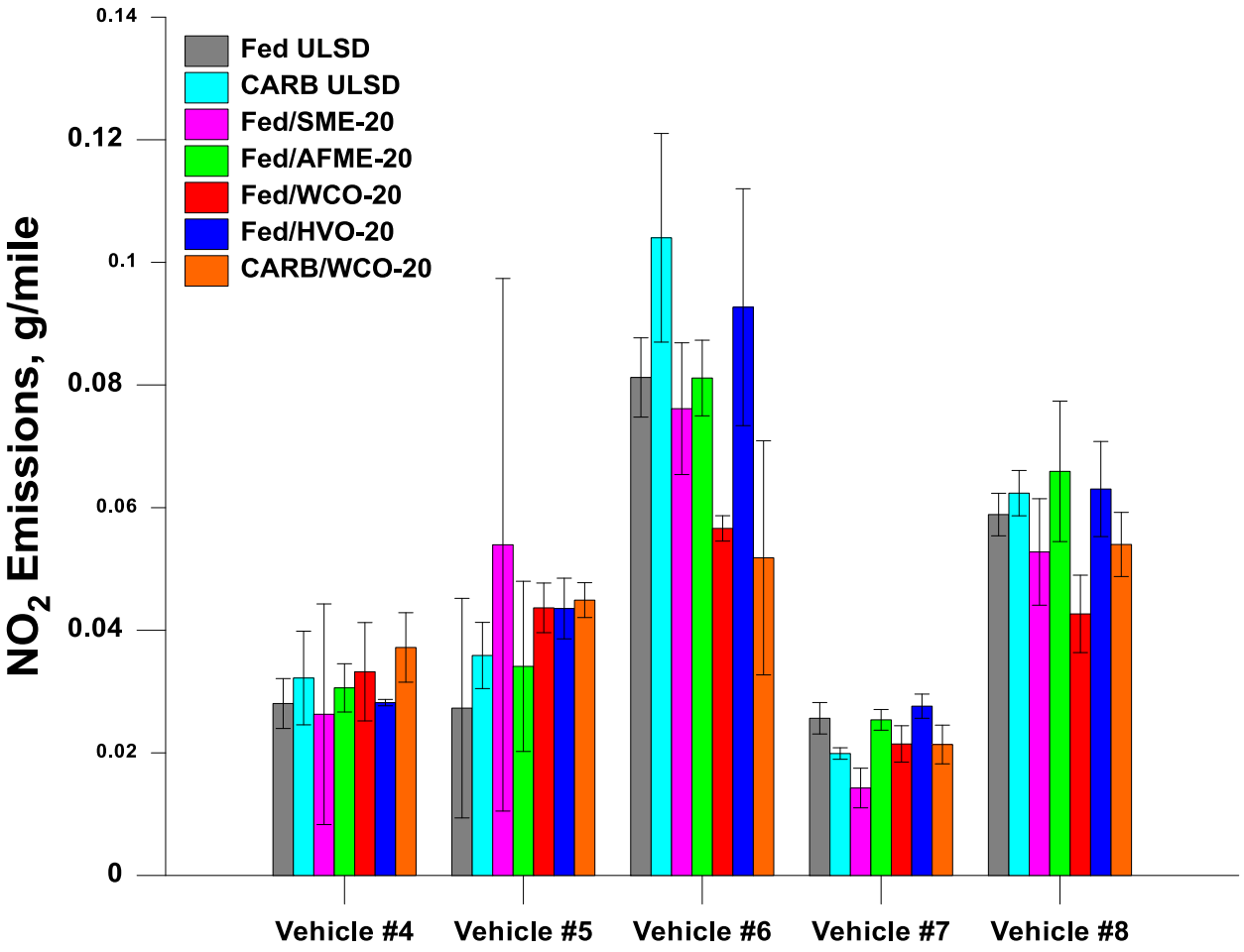


Figure 3-33: NO_2 emissions for Vehicle #4-Vehicle #8 over the FTP

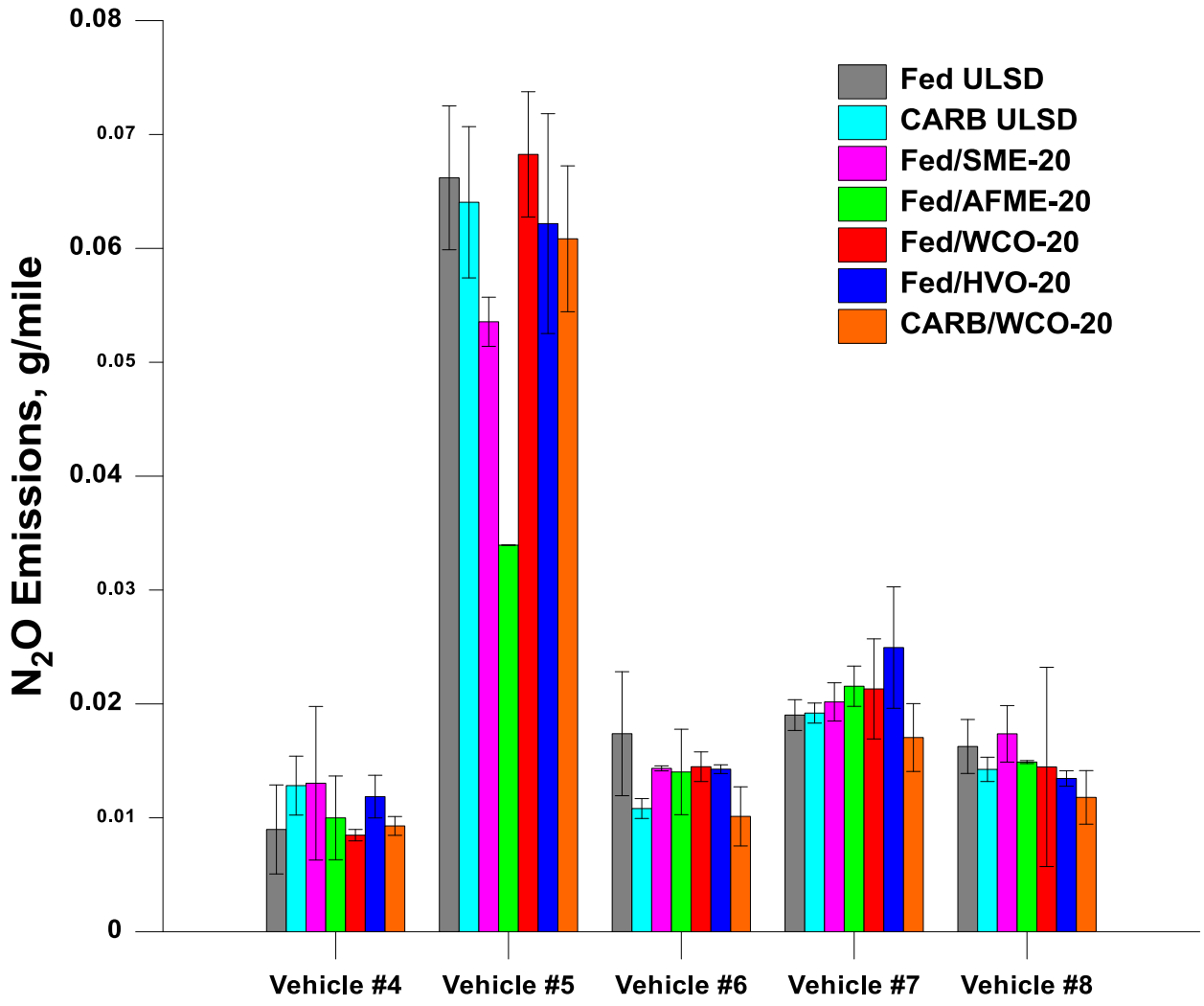


Figure 3-34: N_2O emissions for Vehicle #4-Vehicle #8 over the FTP

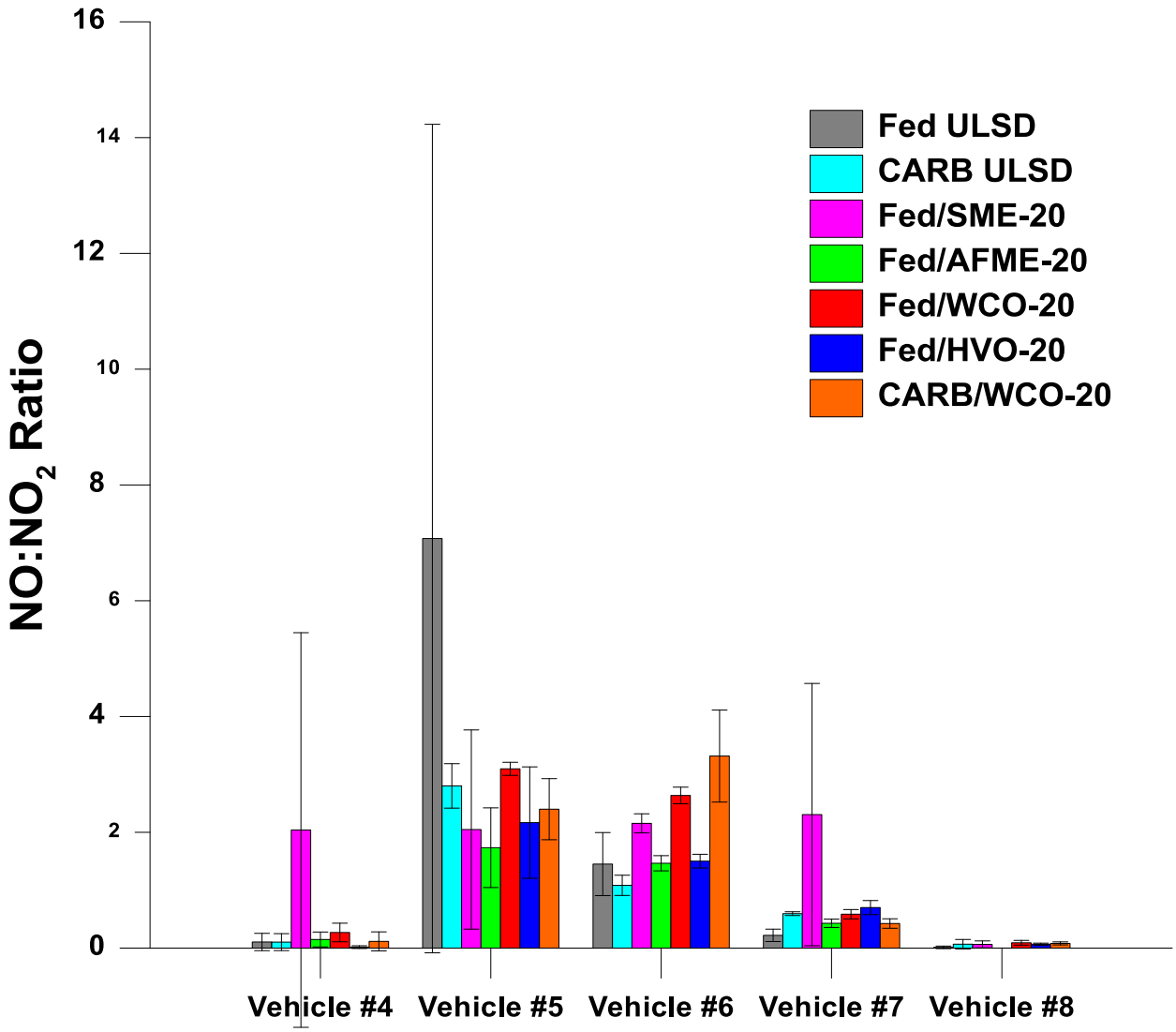


Figure 3-35: NO:NO_2 ratio for Vehicle #4-Vehicle #8 over the FTP

3.13 Regeneration Testing Results

The regeneration of the DPF is of particular interest because it requires a diesel engine to operate in very different regimes with different control requirements than normal operation. The regeneration event typically requires temperatures greater than 550ºC across the DPF. The need for regeneration is triggered by an increased pressure drop across the DPF, which is indicative of soot loading, but the timing of the actual regeneration event is a strong function of the vehicle's driving pattern. Generally, the regeneration is initiated under high speed driving conditions, since temperatures are already higher. The high exhaust temperatures required for the regeneration are created by retarding the main fuel injection and introducing a post-injection of fuel in the exhaust manifold before to the DPF. The combination of main injection retard and post-injection can be used to increase exhaust temperatures without introducing additional torque. Changing the injection parameters leads to increased DOC inlet temperatures directly which may cause a significant increase in HC, which reacts over the DOC to provide additional heat to the DPF (Campbell et al., 2006; Beatrice et al., 2012).

Regeneration emissions testing was conducted on Vehicle #1 and Vehicle #3 on the Federal ULSD and the Fed/SME-20 blend over the HWFET cycle. For each fuel/vehicle combination, two DPF regeneration emission tests were performed over the HWFET, while a single run was

performed on each vehicle on Federal ULSD over the HWFET to provide baseline measurements for comparison purposes. It should be noted that no DPF regeneration occurred during the baseline testing over the HWFET for any vehicle. For Vehicle #1, three DPF regeneration emissions measurements were made on the Fed/SME-20 blend as a result of CPC malfunctions during the first DPF regeneration test. All the DPF regeneration events had different characteristics; much of this variability was due to the duration of the DPF regeneration events, since the same protocol was used for all vehicles/fuels combinations. For Vehicle #1, the first regeneration event on the Federal ULSD lasted approximately 17 minutes and the second event lasted 11 minutes. For Vehicle #1 on the biodiesel blend, the first regeneration event lasted about 16 minutes, the second event lasted 22 minutes, and the third event lasted 16 minutes. For Vehicle #3, the first regeneration event on the Federal ULSD lasted 12 minutes and the second event lasted 9 minutes; For Vehicle #3 on the biodiesel blend, the first regeneration event lasted about 11 minutes and the second event lasted 7 minutes.

Figure 3.36 (a-b) and Figure 3.37 (a-b) show the regulated emissions and CO_2 emissions and fuel economy for Vehicle #1 and Vehicle #3, respectively, during the DPF regeneration events over the HWFET. For Vehicle #1, the regulated emissions for both fuels during the DPF regeneration events were significantly higher than for the baseline HWFET measurement. The use of biodiesel resulted in marked increases in THC, CH_4, and NMHC emissions compared to Federal ULSD. CO, NO_x and CO_2 emissions during DPF regenerations were comparable between fuels within the experimental variability. As expected, fuel economy was lower for both fuels during DPF regeneration; the biodiesel blend exhibited slightly higher fuel economy compared to Federal ULSD. For Vehicle #3, the application of biodiesel blends led to marked increases in THC, NMHC, CO, NO_x, and CO_2 emissions compared to Federal ULSD. It should be emphasized that NO_x emissions for Vehicle #3 were approximately three times higher than those seen for Vehicle #1. This result was unexpected since NO_x emissions were at the same levels for both vehicles during normal FTP operation. Similarly, fuel economy was lower for both fuels during the regeneration testing; the biodiesel blend showed lower fuel economy compared to Federal ULSD. It is worth noting that the higher CH_4 emissions for both vehicles could be explained by the higher temperatures of the exhaust gas during the DPF regeneration, thus increasing oxidation of higher hydrocarbons on the oxidation catalyst. This could lead to an increased percentage of CH_4, which is more difficult to oxidize. For Vehicle #1, most of the THC was found to be CH_4. Also, the higher tailpipe CO emissions during DPF regenerations for both vehicles are associated with partial oxidation of carbon to CO rather than to CO_2. The higher THC and CO emissions for the biodiesel blend during the regeneration process might indicate poorer combustion efficiency relative to Federal ULSD.

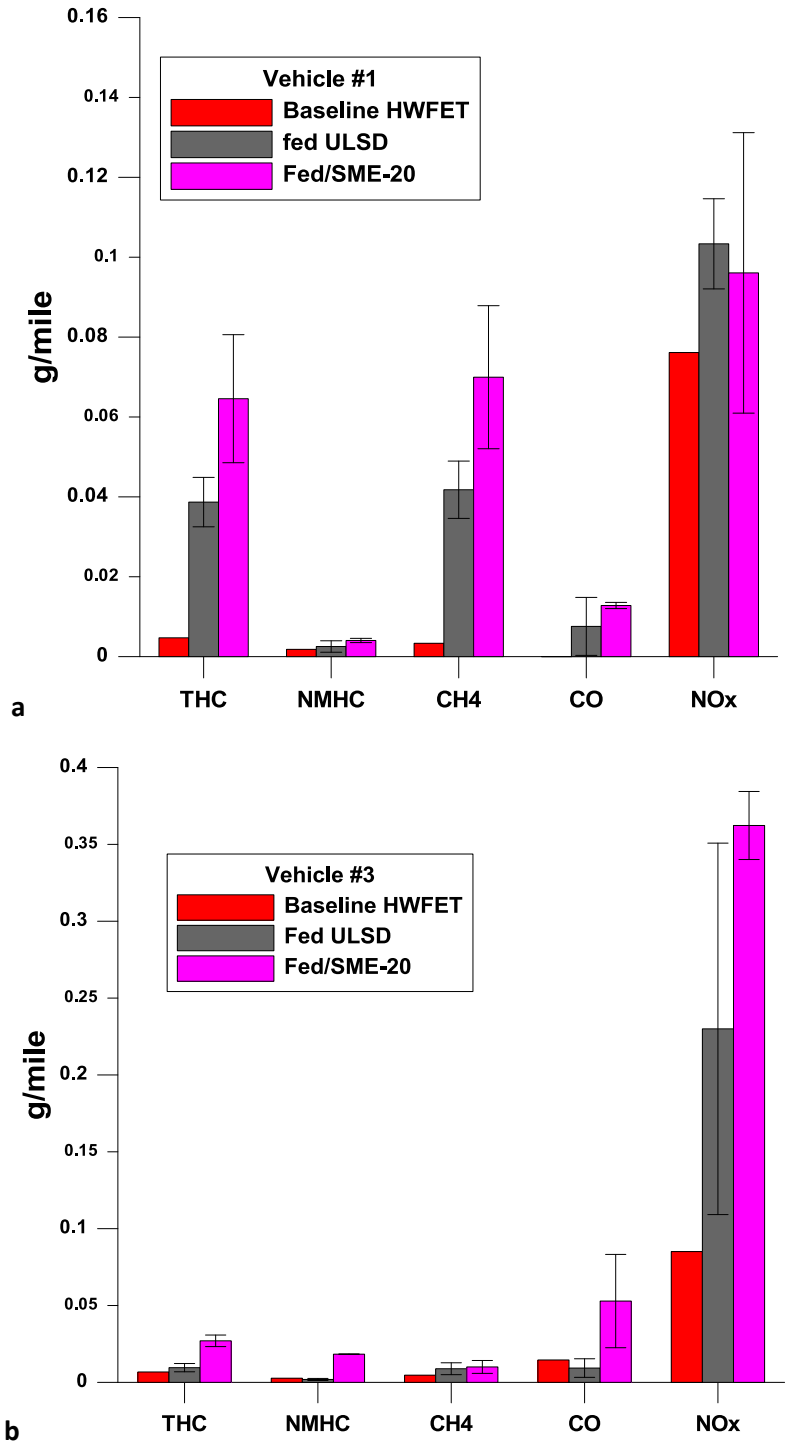


Figure 3-36 (a-b): Regulated emissions for Vehicle #1 (a) and Vehicle #3 (b) during regeneration emissions testing over the HWFET

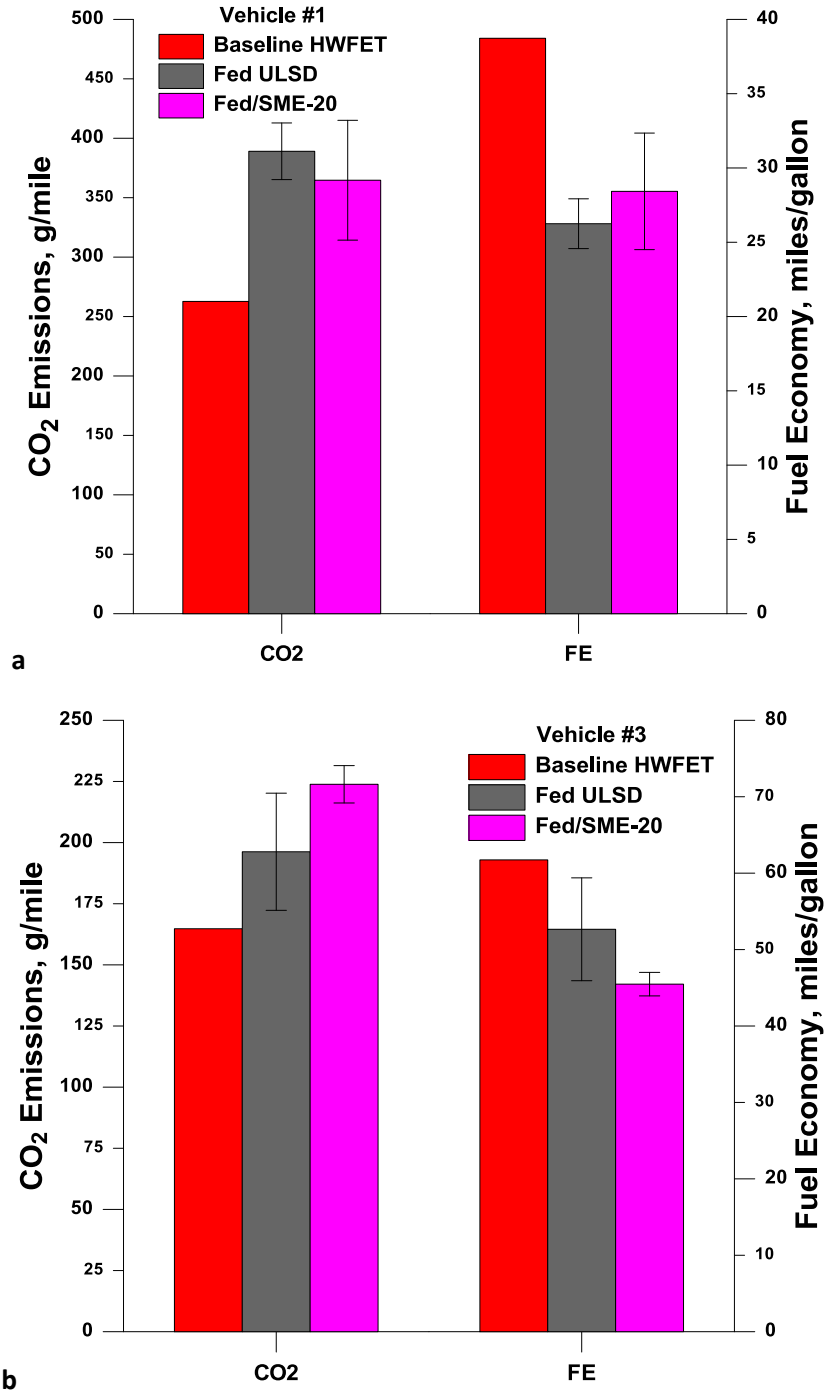


Figure 3-37 (a-b): CO_2 emissions and fuel economy for Vehicle #1 (a) and Vehicle #3 (b) during regeneration emissions testing over the HWFET

Figure 3.38 presents the PM mass emissions for both vehicles during the DPF regeneration events. For comparison, the baseline HWFET measurement on Federal ULSD is included. No Teflon® filters were collected during the baseline HWFET cycle for Vehicle #1. Based on the PM mass results obtained from Vehicle #3 testing, both fuels led to significant increases in PM emissions compared to the baseline test. Also, PM mass emissions were considerably higher for both fuels during the regeneration emissions testing compared to the FTP PM mass emissions for both vehicles. The use of soy-based biodiesel blend for Vehicle #3 resulted in a statistically significant 40% PM mass reduction compared to Federal ULSD. The reductions in PM mass emissions for the biodiesel blend could be due to the presence of oxygen content and the absence of aromatics compounds in the methyl ester.

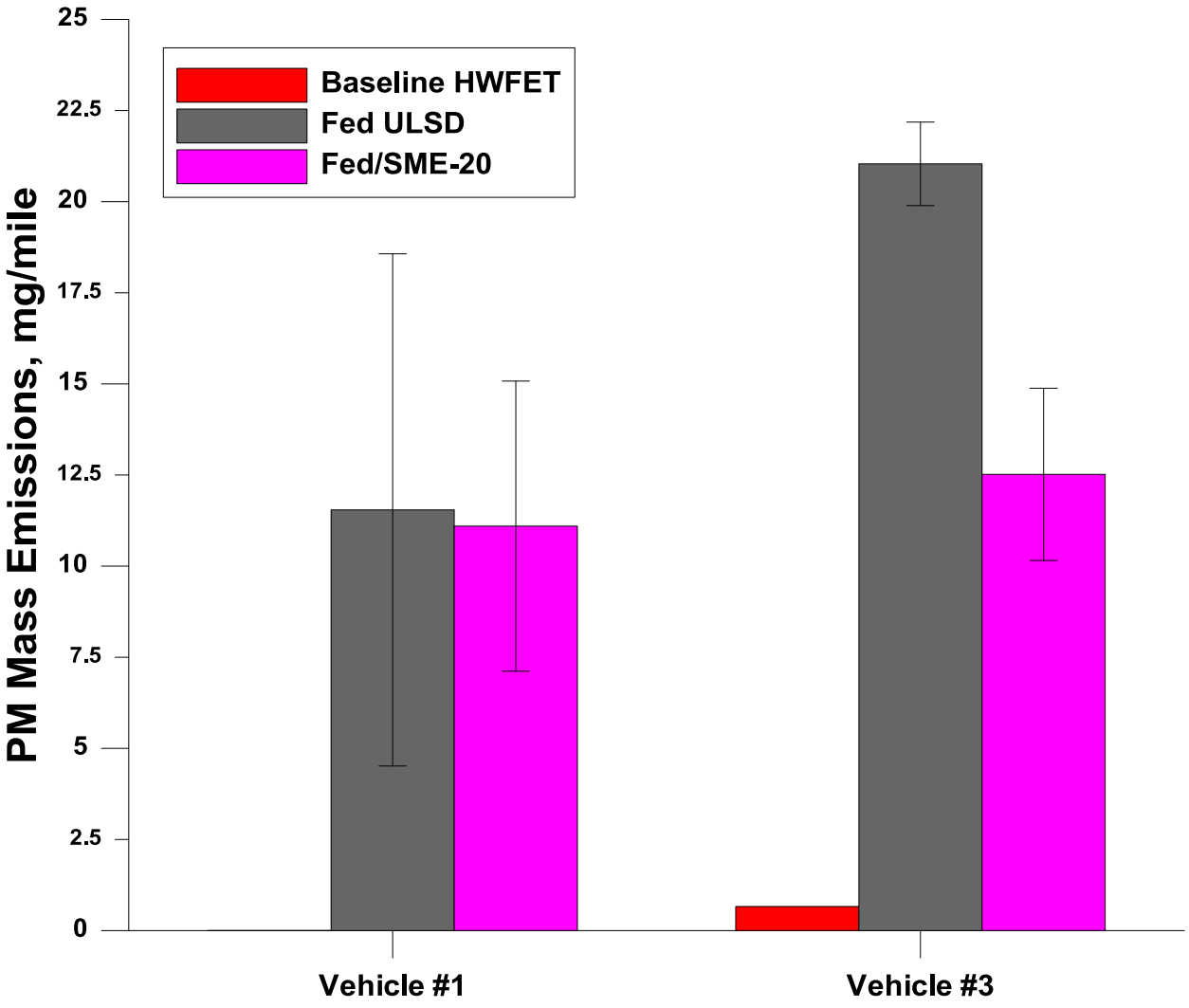


Figure 3-38: PM mass emissions during regeneration emissions testing over the HWFET

Total particle number emissions are shown in Figure 3.39. Overall, particle number emissions were significantly higher for both fuels during the regeneration events than the baseline HWFET testing, with particle number emissions for the biodiesel blend for Vehicle #1 being higher than those of Vehicle #3. For Vehicle #1, the use of biodiesel resulted in a marked increase in particle number emissions compared to Federal ULSD. This increase was on the order of 390% and was also statistically significant. For Vehicle #2, a decrease of 28% in particle number emissions was observed for the biodiesel blend compared to Federal ULSD. Overall, total particle number emissions during regeneration testing were several orders of magnitude higher compared to those emitted during standard FTP operation. This observation is in qualitative agreement with the findings from Giechaskiel et al. (2007), Bikas and Zervas (2007), Dwyer et al., (2010), and Mamakos et al. (2013). The elevated total particle population could be attributed to the formation of volatile nanoparticles during DPF regeneration. These volatile particles were generally found to peak at approximately 10 nm (mobility diameter) and have been associated to the formation of sulfates (Bergmann et al., 2009). Another factor that may have contributed to the increased particle number emissions during regeneration testing is treduced efficiency of DPF filtration caused by oxidation (and thus removal) of accumulated soot, which also filters airborne particles (Konstantopoulos et al., 2007).

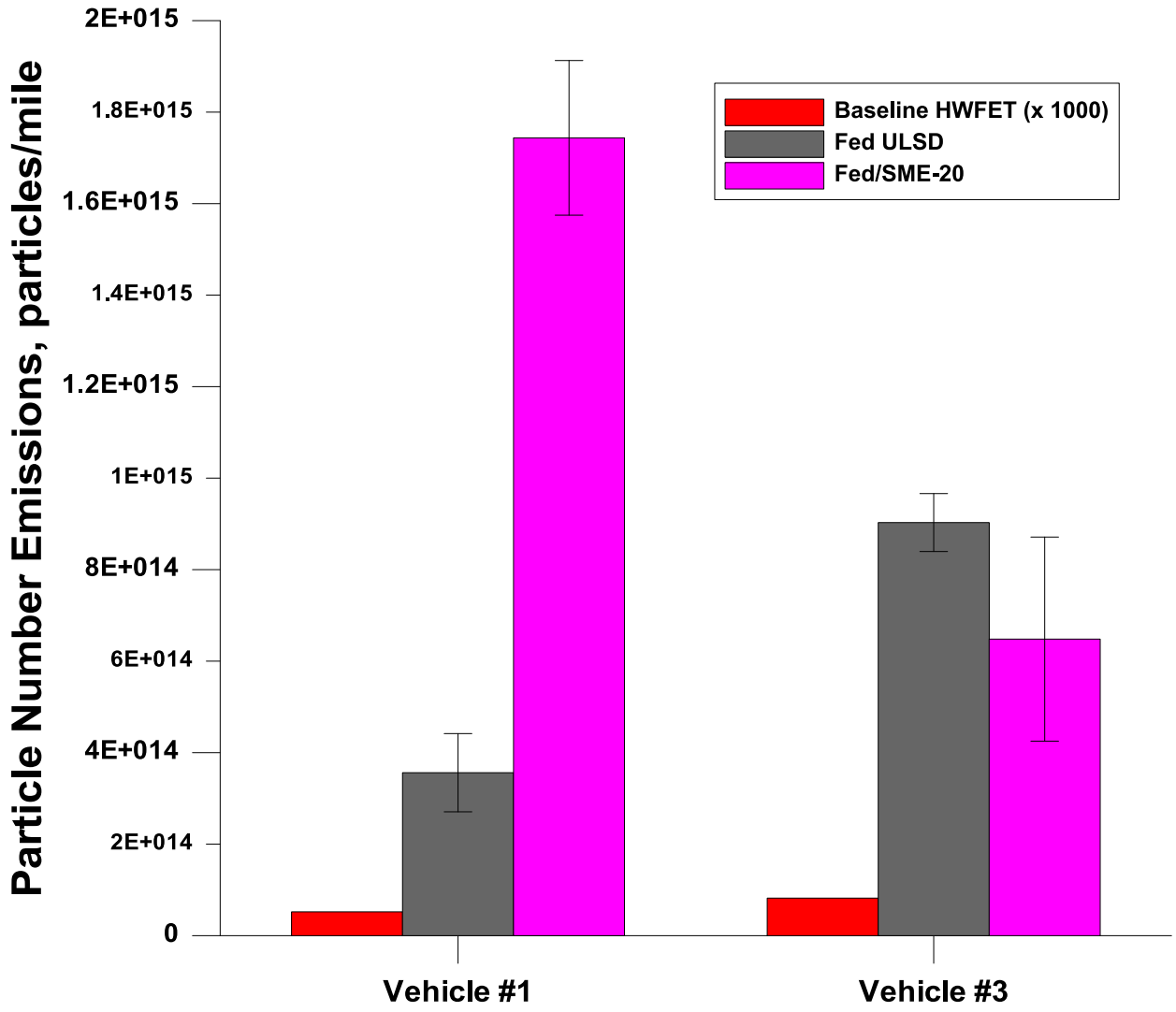
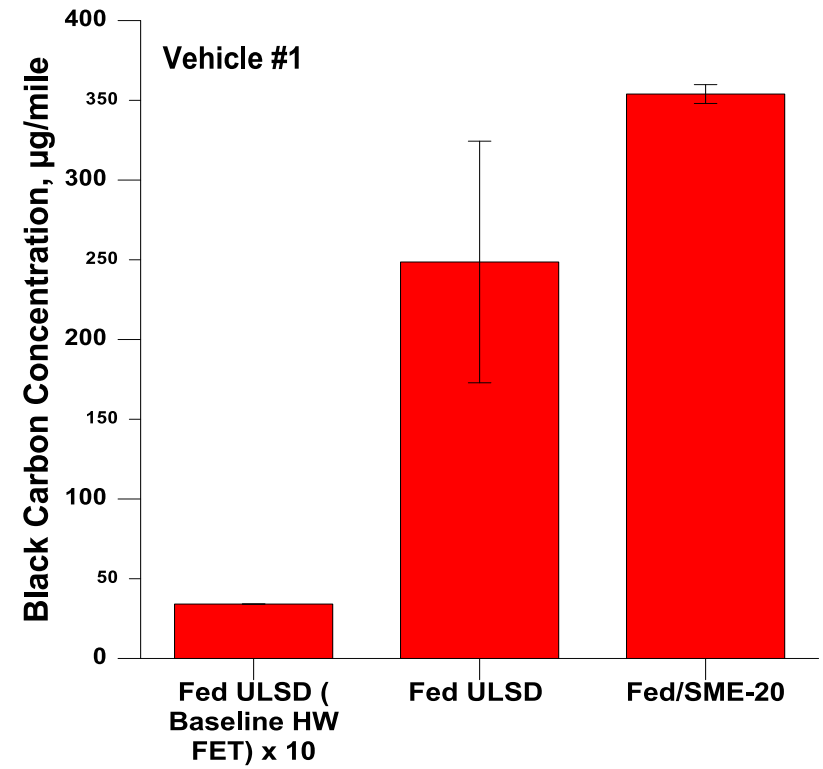
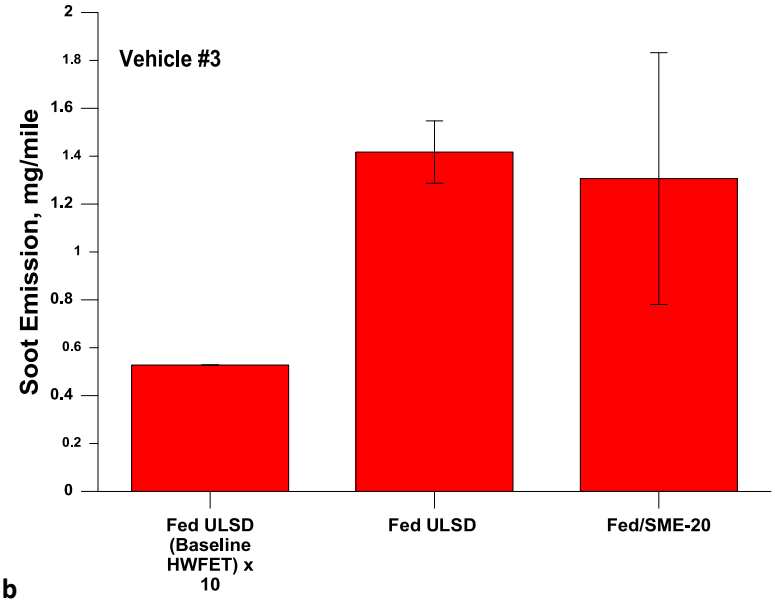


Figure 3-39: Particle number emissions during regeneration emissions testing over the HWFET

Figure 3.40 (a-b) shows the black carbon concentrations for Vehicle #1 during the DPF regeneration event. It should be mentioned that the MAAP instrument wasn't functional during the regeneration emissions testing for Vehicle #3, so no black carbon emissions are available for this vehicle. However, real-time soot emission measurements were made for Vehicle #3 using an AVL MSS instrument. For Vehicle #1, black carbon concentrations were found to be significantly higher during the regeneration emissions testing, with the biodiesel blend showing an increase in black carbon emissions of 42% compared to Federal ULSD. This increase in black carbon emissions for the biodiesel blend was in line with the increase observed for the total particle number emissions compared to Federal ULSD. For Vehicle #3, real-time soot emissions were higher for both fuels during the regeneration testing compared to the baseline testing. No significant differences were seen between the fuels during regeneration. In addition, comparing the two instruments together, it was seen that soot and black carbon emission factors correlated well. However, a closer analysis of real-time soot and black carbon results showed the opposite phenomenon, which could be ascribed to the different techniques used by the AVL MSS and the MAAP instruments.



a



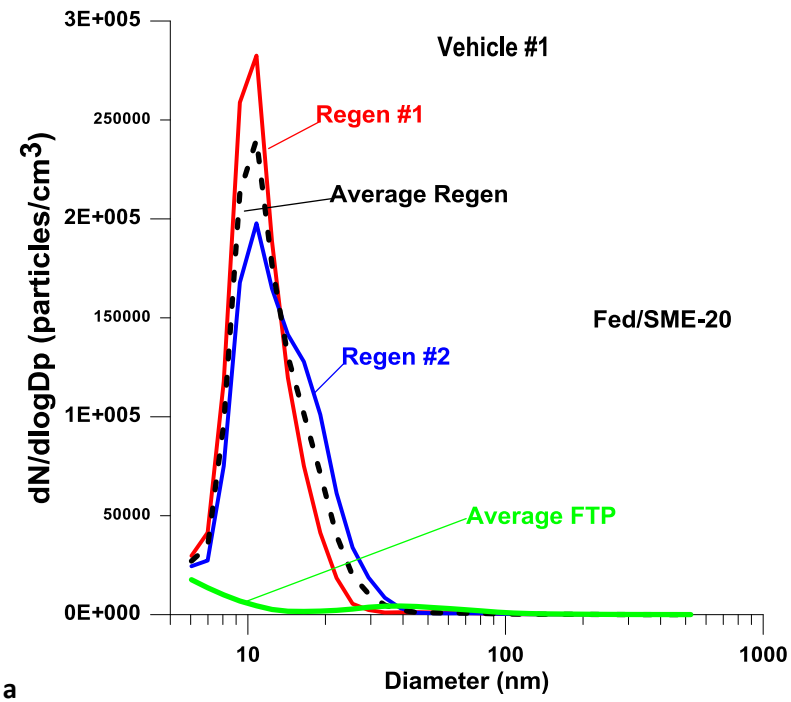
b

Figure 3-40 (a-b): Black carbon concentrations for Vehicle #1 (a) and real-time soot emissions for Vehicle #3 (b) during regeneration emissions testing over the HWFET

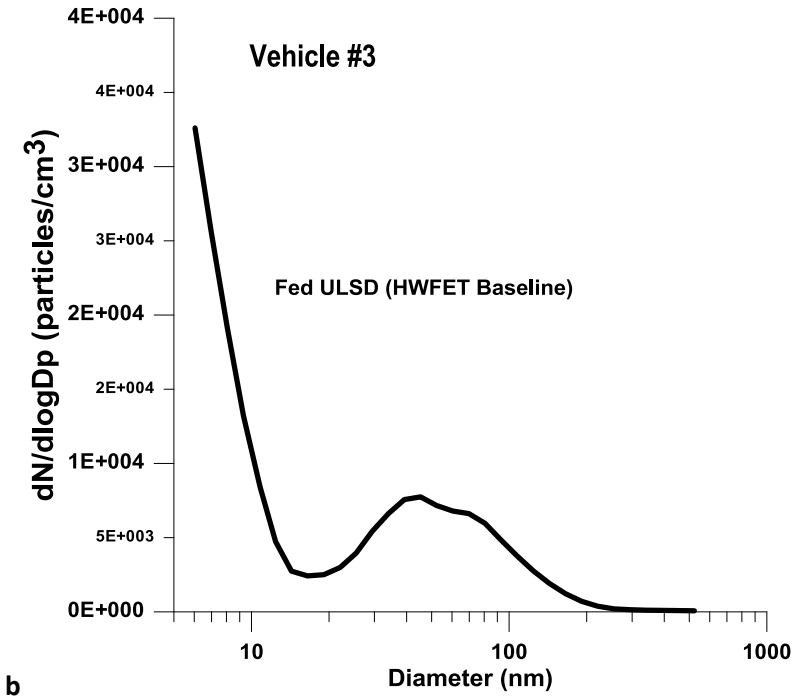
Particle size distributions are shown in Figure 3.41 (a-c). It should be mentioned that particle size distributions measurements were not made for Vehicle #1 on Federal ULSD during regeneration testing, as the EEPS was not available at that time. The displayed data show that during regeneration events, a substantial nucleation mode was apparent. Diesel engine nucleation mode particles likely consist of water, sulfate, and/or volatile hydrocarbons, and it is well known that dilution ratio, temperature and residence time have profound effects upon the rate of nucleation of these species and hence upon the size and concentration of nucleation mode particles

(Campbell et al., 2006). For this study, these particles may have formed from sulfate nuclei with condensed hydrocarbons. Probable sources of sulfates are sulfur adsorbed on the soot, sulfur trapped in the DPF, and sulfur in the aftertreatment devices. More specifically, a possible explanation for nucleation mode particles found in the tailpipe might be the ability of the DPF to store sulfur compounds that can be released and oxidized to SO_3/H_2SO_4 during regeneration due to the increased temperature (Bergmann et al., 2009). Moreover, sulfur from the fuel (mainly from Federal ULSD) that is injected into the catalyst to heat the DPF may play an important role.

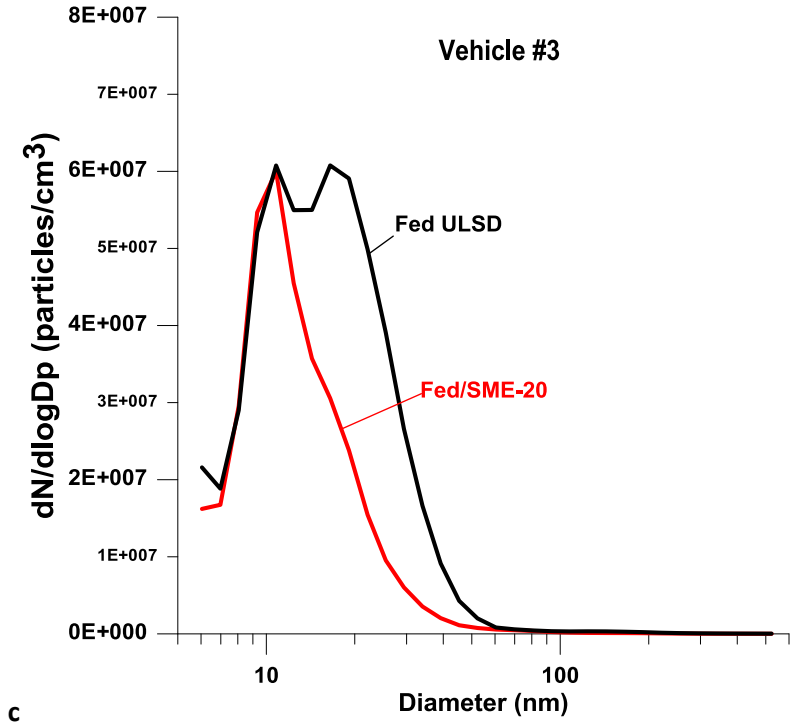
For Vehicle #3, nucleation mode particle concentrations were found to be many orders of magnitude higher than those of Vehicle #1, a result inconsistent with the lower particle number emissions observed for the Vehicle #3 relative to Vehicle #1. It is possible that DPF loading for Vehicle #3 tests was higher, although the regeneration event for the Vehicle #3 was shorter in duration than for Vehicle #1. For a higher DPF loading more sulfur (e.g., from lubricant oil) is accumulated, which in turn leads to a formation of nucleation particles during regeneration. It should be also emphasized that the use of biodiesel had no effect on particle size distributions for Vehicle #3.



a



b



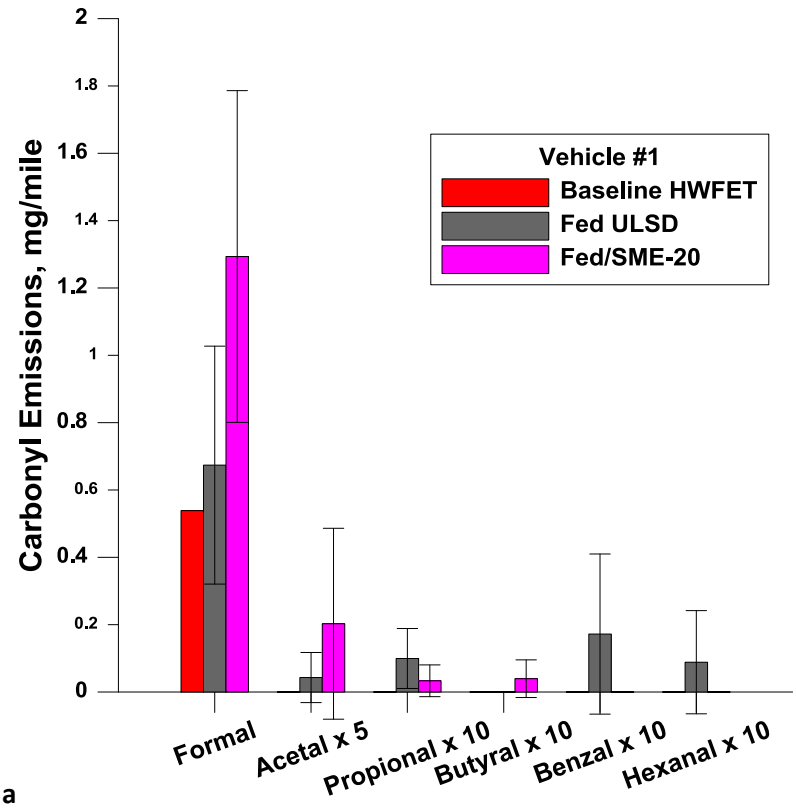
c

Figure 3-41 (a-c): Particle size distributions for Vehicle #1 (a) and Vehicle #3 (b, c) during regeneration emissions testing over the HWFET

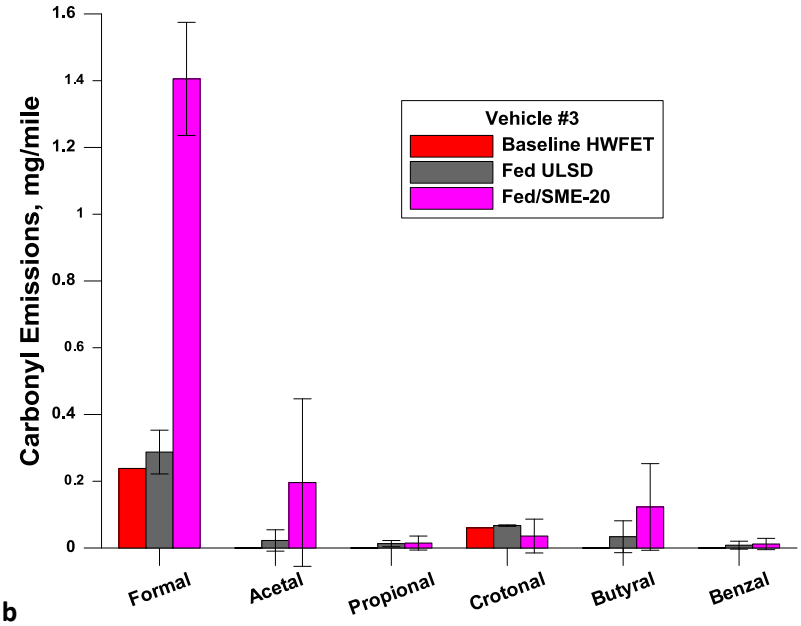
Emissions of carbonyl compounds for both vehicles during regeneration emissions testing over the HWFET are shown in Figure 3.42 (a-c). For both vehicles, the most abundant carbonyl compound in the exhaust during the regeneration event was formaldehyde, followed by acetaldehyde. For Vehicle #1, heavier carbonyls were also present in the exhaust, but in lesser amounts, with propionaldehyde, butyraldehyde, benzaldehyde, and hexanaldehyde being detected mainly during regeneration events, but not in the baseline HWFET testing. The application of biodiesel showed increases of 92% and 372%, respectively, for formaldehyde and acetaldehyde emissions compared to Federal ULSD, although these differences were not statistically significant. For Vehicle #3, some heavier carbonyl compounds, including those of

propionaldehyde, crotonaldehyde, butyraldehyde, and benzaldehyde, were detected in the exhaust during regeneration testing, but in very low concentrations. It is worth noting that heavier carbonyls for the Vehicle #3 were found at considerably higher levels than those of Vehicle #1, while formaldehyde and acetaldehyde were at comparable levels. Similar to Vehicle #1 regeneration emissions testing, the use of biodiesel resulted in marked increases in formaldehyde (389%) and acetaldehyde (767%) emissions compared to Federal ULSD, with the increase in formaldehyde emissions being statistically significant. The increases in carbonyl emissions with biodiesel relative to Federal ULSD during regeneration testing can be confirmed by the total carbonyl emissions results, as shown in Figure 3.40c. Total carbonyls appeared in higher concentrations during regeneration testing compared to baseline testing for both vehicles, with the soy-based biodiesel resulting in marked increases in total carbonyl emissions. For Vehicle #3, the biodiesel blend showed a statistically significant increase of 313% in total carbonyl emissions compared to Federal ULSD.

In general, the increase in carbonyl emissions with the biodiesel blend could be due to the oxygen content in the ester molecule, which can promote the formation of aldehydes during combustion (Correa and Arbilla, 2008). During DPF regeneration, the DPF effectively oxidized most carbonyl compounds with the notable exception of formaldehyde. During the regeneration events, there was a significant increase in THC in the exhaust due to the fuel injection, which promotes reactions over the DOC to provide additional heat to the DPF. It is reasonable to assume that some THC escaped from the DOC/DPF system, as the aftertreatment may not have sufficient capacity to fully oxidize the additional THC during the regeneration event. This observation is also in line with the THC results shown in Figure 3.34 (a-b). It is therefore possible that some heavier hydrocarbon species, including higher molecular-weight aldehydes, were related to hydrocarbons that did not fully oxidize in the aftertreatment system. In the case of formaldehyde, it is possible that the higher formaldehyde emission concentrations were due to different formation pathways, since formaldehyde is an intermediate oxidation product from other aldehydes and hydrocarbons within the DPF. In addition, formaldehyde is an intermediate step in the oxidation of methane under high temperature conditions and across the DOC; thus, the high concentrations observed for methane emissions during the DPF regeneration events for both vehicles may have contributed to the formation of formaldehyde emissions.


Carbonyl Emissions, mg/mile
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Vehicle #1
Baseline HWFET
Fed ULSD
Fed/SME-20
Formal
Acetal x 5
Propional x 10
Butyral x 10
Benzal x 10
Hexanal x 10

a


Carbonyl Emissions, mg/mile
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Vehicle #3
Baseline HWFET
Fed ULSD
Fed/SME-20
Formal
Acetal
Propional
Crotonal
Butyral
Benzal

b

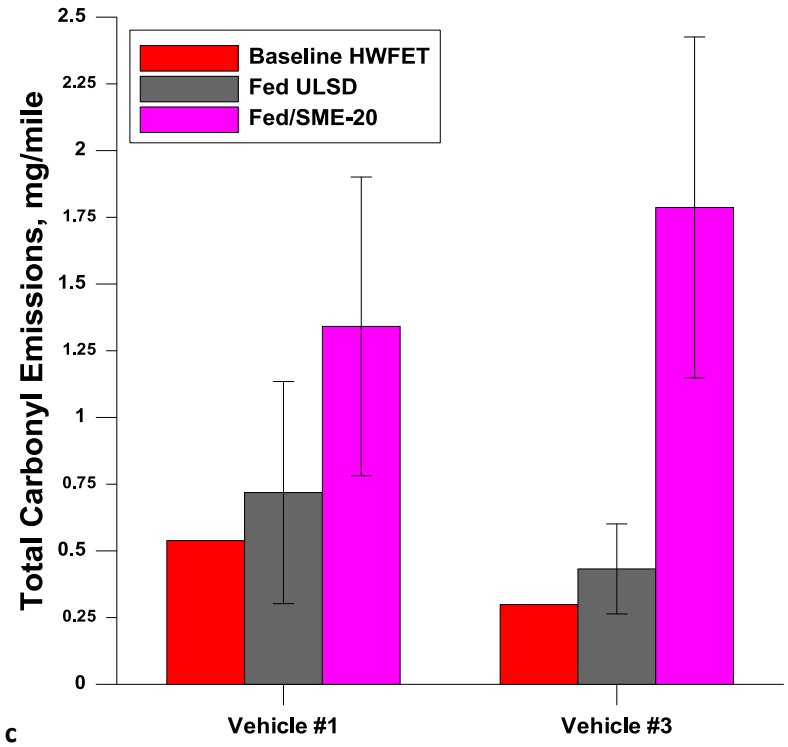


Figure 3-42 (a-c): Individual carbonyl emissions for Vehicle #1 (a) and Vehicle #3 (b) and total carbonyl emissions for both vehicles (c) during regeneration emissions testing over the HWFET

Figure 3.43 shows the total gas-phase PAH emissions for the two vehicles during the DPF regeneration events. Table D33 (see Appendix D) lists the individual gas-phase PAH compounds for both vehicles/fuels combinations over the HWFET. For both vehicles, the aromatic compounds, C_{12} biphenyls and the C_{13} methylbiphenyls (2-methylbiphenyl, 3-methylbiphenyl, and 4-methylbiphenyl) were by far the most predominant species in the gas-phase followed by naphthalene, methyl- and ethylnaphthalenes, fluorene, 9-fluorenone, phenanthrene, xanthone, fluoranthene, and pyrene. Compounds with higher molecular weights were found at very low levels, or were below the detection limits. Total gas-phase PAH emissions for Federal ULSD were comparable between the regeneration and baseline testing. The use of biodiesel resulted in an increase of 55% in total gas-phase PAH emissions compared to Federal ULSD for Vehicle #3, although these differences were not statistically significant. For Vehicle #1, the gas-phase PAHs were comparable within the experimental variability for the Federal ULSD and the soy-based biodiesel.

The use of soy-based biodiesel blend led to sharp increases in most gas-phase PAH species during regeneration emissions testing compared to Federal ULSD. Although this observation holds true for both vehicles, this trend isn't reflected in the total gas-phase PAH emissions for Vehicle #1. This was because, while lighter gas-phase PAHs were dominant for the biodiesel blend, the biphenyls and methylbiphenyl compounds were the dominant gas-phase PAHs for the Federal ULSD, and they dictated the total gas-phase PAH distribution for the Federal ULSD. Specifically, the use of biodiesel led to marked increases in gas-phase naphthalene, methyl- and ethylnaphthalenes, acenaphthene, fluorene, and methylfluorenes. In most cases, these compounds were found in significantly higher concentrations during the regeneration emissions testing compared to the baseline HWFET testing. For Vehicle #1, the emissions for the biodiesel blend were higher in phenanthrene, methylphenanthrenes, anthracene, anthraquinone, and fluoranthene. This phenomenon was not observed for Vehicle #3, where levels of these

compounds were lower with the biodiesel blend than Federal ULSD during regeneration emissions testing.

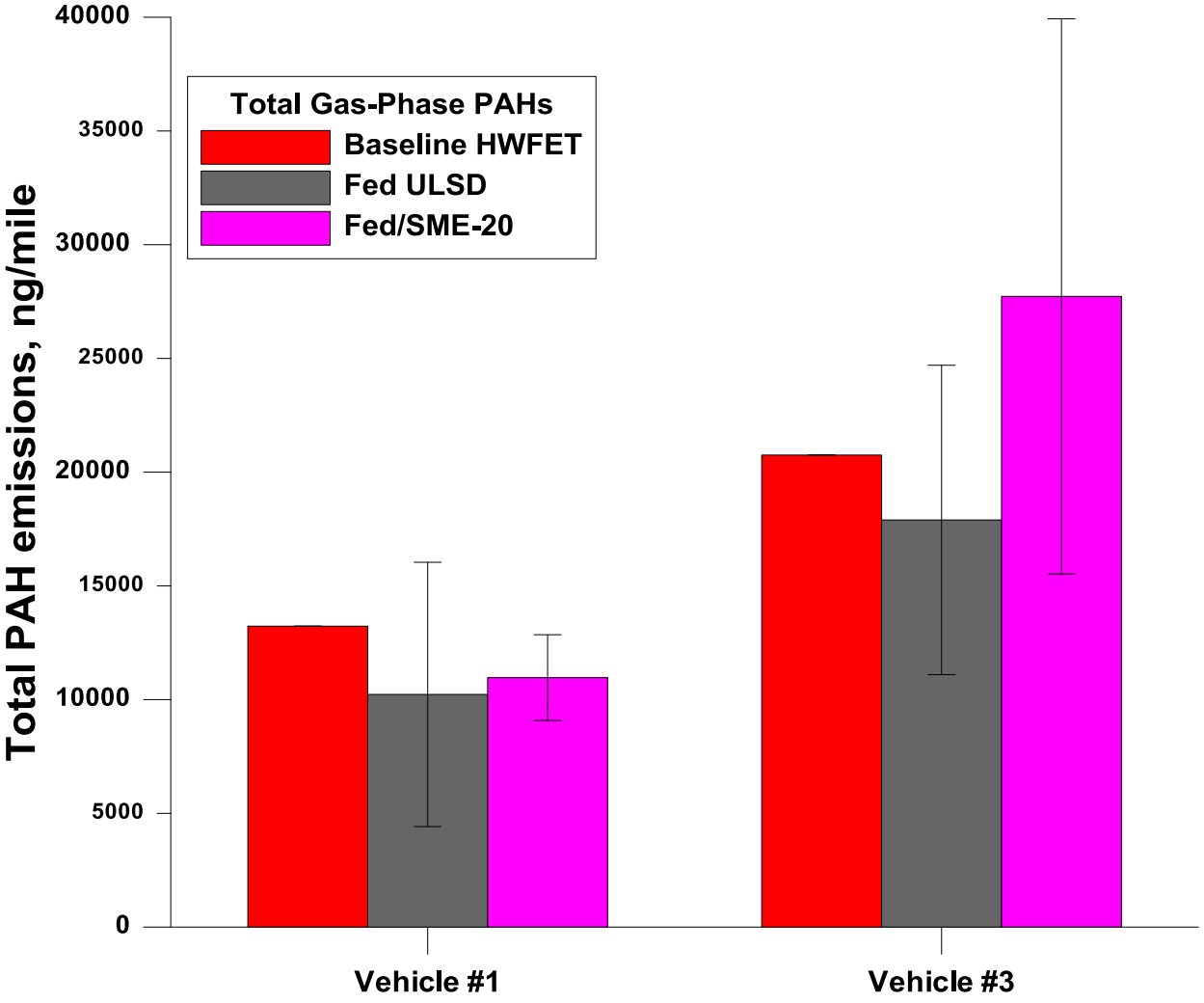


Figure 3-43: Total gas-phase PAH emissions during regeneration emissions testing over the HWFET cycle

Although the gas-phase PAHs dominate the overall emissions of PAHs, the particle-phase PAHs include most of the probable human carcinogenic compounds (Armstrong et al., 2004). Figure 3.44 shows the total particle-phase PAH emissions for both vehicles during regeneration emissions testing over the HWFET. Table D34 (see Appendix D) lists the individual gas-phase PAHs during the regeneration emissions testing and baseline testing for both vehicles on the Federal ULSD and Fed/SME-20. The PAHs with three or four rings were the predominant species in the particle-phase for both vehicles during regeneration testing, including phenanthrene, methylphenanthrenes, dimethylphenanthrenes, fluoranthene, pyrene, and 4-methylpyrene. Some oxygenated PAHs were also found in the exhaust in relatively high concentrations, including 9-fluorenone, xanthone, and anthraquinone. Lighter PAHs with two rings were also detected in the particle-phase in considerable concentrations. Naphthalene, methyl- and ethylnaphthalenes, dimethylnaphthalenes, and trimethylnaphthalenes dominated the low molecular-weight particle-phase PAH distribution. The contribution of PAHs with five or more rings from the vehicles during the regeneration emissions testing in the particle-phase distribution was also notable, with benzo(ghi)fluoranthene, benz(a)anthracene, chrysene, 7,12-

dimethylbenz(a)anthracene, benzo(b)fluoranthene, and benzo(e)pyrene showing highest concentrations for both Federal ULSD and Fed/SME-20 blend.

As shown in Figure 3.44, total particle-phase PAHs for both vehicles exhibited increases compared to the baseline testing, in contrast to the gas-phase PAH results. For Vehicle #1, total particle-phase PAHs showed a 53% reduction for the biodiesel blend compared to the federal ULSD, with this difference not being statistically significant. For Vehicle #3, the fuel differences were within the experimental variability of the data. Unlike the gas-phase PAHs, the particle-phase species demonstrated lower oxidation rates in the DOC/DPF system for both vehicles during regeneration testing compared to baseline testing.

The individual particle-phase PAH distribution for Vehicle #1 showed that phenanthrene, methylphenanthrenes, benzo(ghi)fluoranthene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, and benzo(e)pyrene were the PAH species found at higher levels for the biodiesel blend than Federal ULSD during regeneration testing. For Vehicle #3, most PAH species with 3-4 rings showed higher concentrations with biodiesel compared to Federal ULSD, including phenanthrene, anthracene, fluoranthene, pyrene, methylpyrenes, and methylphenanthrenes. Heavier PAHs and some oxygenated compounds showed increases with the use of biodiesel blend during regeneration testing, including benzonaphthothiophene, benzo(ghi)fluoranthene, benz(a)anthracene, chrysene, benzanthrone, benz(a)anthracene-7,12-dione, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(e)pyrene, benzo(a)pyrene, indeno[123-cd]pyrene, benzo(ghi)perylene, triphenylene, and coronene. Interestingly, these high molecular-weight PAHs were also found in higher concentrations than in the baseline testing for Vehicle #3. For Vehicle #3, the use of biodiesel also increased the light 2-ring PAH species, such as naphthalene and methylnaphthalenes, relative to Federal ULSD. For Vehicle #3, it is possible that the oxygenate fraction in the fuel and the absence of aromatics did not play a significant role in reducing PAH emissions. It is also possible that the influence of biodiesel source material (degree of unsaturation) under high combustion temperatures contributed to PAH formation during regeneration testing. Overall, these results indicate that part of the PAHs found may not have come from the engine. They may instead have originated from excess fuel or hydrocarbons injected prior to the DPF during regeneration, via either combustion of excess hydrocarbons or incomplete oxidation in the DOC/DPF, even at the higher temperature condition. Therefore, it is reasonable to hypothesize that the PAHs produced under regeneration conditions are different from those produced from combustion in the engine, thus changing the PAH emission profile.

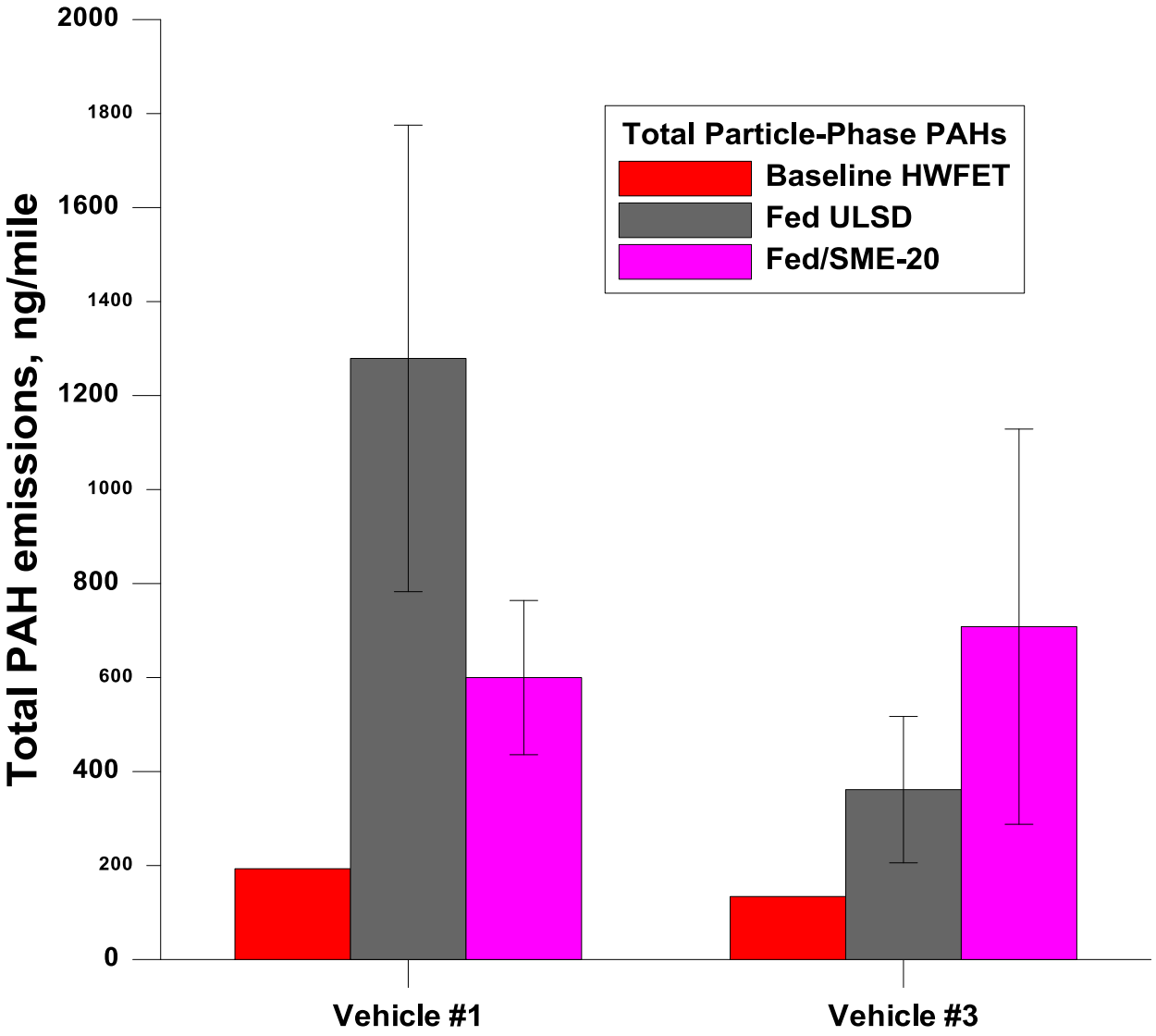


Figure 3-44: Total particle-phase PAH emissions during regeneration emissions testing over the HWFET cycle

Figure 3.45 shows the total gas-phase nitro-PAH emissions for both vehicles during DPF regeneration and baseline testing over the HWFET. Table D35 (see Appendix D) lists the individual gas-phase nitro-PAH species along with their corresponding standard deviations. Similar to normal FTP testing, a total of 36 species of nitro-PAHs in gas-phase were analyzed during regeneration emissions testing. The most abundant species in the gas-phase for both vehicles were 1-nitronaphthalene, 2-nitronaphthalene, 1-methyl-6-nitronaphthalene, and 3-nitrophenanthrene. Heavier nitro-PAH species, including 1-nitropyrene, were nearly below the detection limit in the gas-phase. For Vehicle #1, total gas-phase nitro-PAHs trended lower for both fuels during regeneration testing compared to the baseline testing. This result generally indicates higher conversion efficiencies of these species in the DPF during regeneration testing. The use of biodiesel showed a 54% reduction in total gas-phase nitro-PAH emissions compared to Federal ULSD, but this difference was not statistically significant. For Vehicle #3, total gas-phase nitro-PAHs during DPF regeneration trended higher than those of the baseline testing, but not at a statistically significant level, while the large variability for the biodiesel blend made comparisons with the Federal ULSD difficult.

A more detailed analysis on the individual gas-phase nitro-PAHs suggests that the majority of these species exhibited enhanced emissions during regeneration testing for both vehicles. In particular, there were cases where certain species, such as 1-methyl-6-nitronaphthalene, 4-nitrobiphenyl, and 9-nitroanthracene, were undetectable for the baseline testing but not for the regeneration testing. Most notably, these species showed an increase with the use of biodiesel blend relative to Federal ULSD for both vehicles. DPFs can support nitration reactions, but they can also catalyze nitro-PAH degradation through oxidation (Heeb et al., 2008; Carrara and Niessner, 2011). During regeneration events, where typical temperatures across the DPF can exceed 500°C, even larger PAHs may volatilize, leading to gas-phase reactions not observed at ambient conditions. Vapor pressures of nitro-PAHs are two to three orders of magnitude lower than those of their parent PAHs, and their reactivities are assumed to be higher. Therefore, longer residence times and higher conversion efficiencies are expected, unless nitro-PAHs do form de novo in the DPF (Heeb et al., 2008; Heeb et al., 2010). Under the present test conditions, the results indicated that most nitro-PAH species formed de novo in the DPFs during regeneration testing.

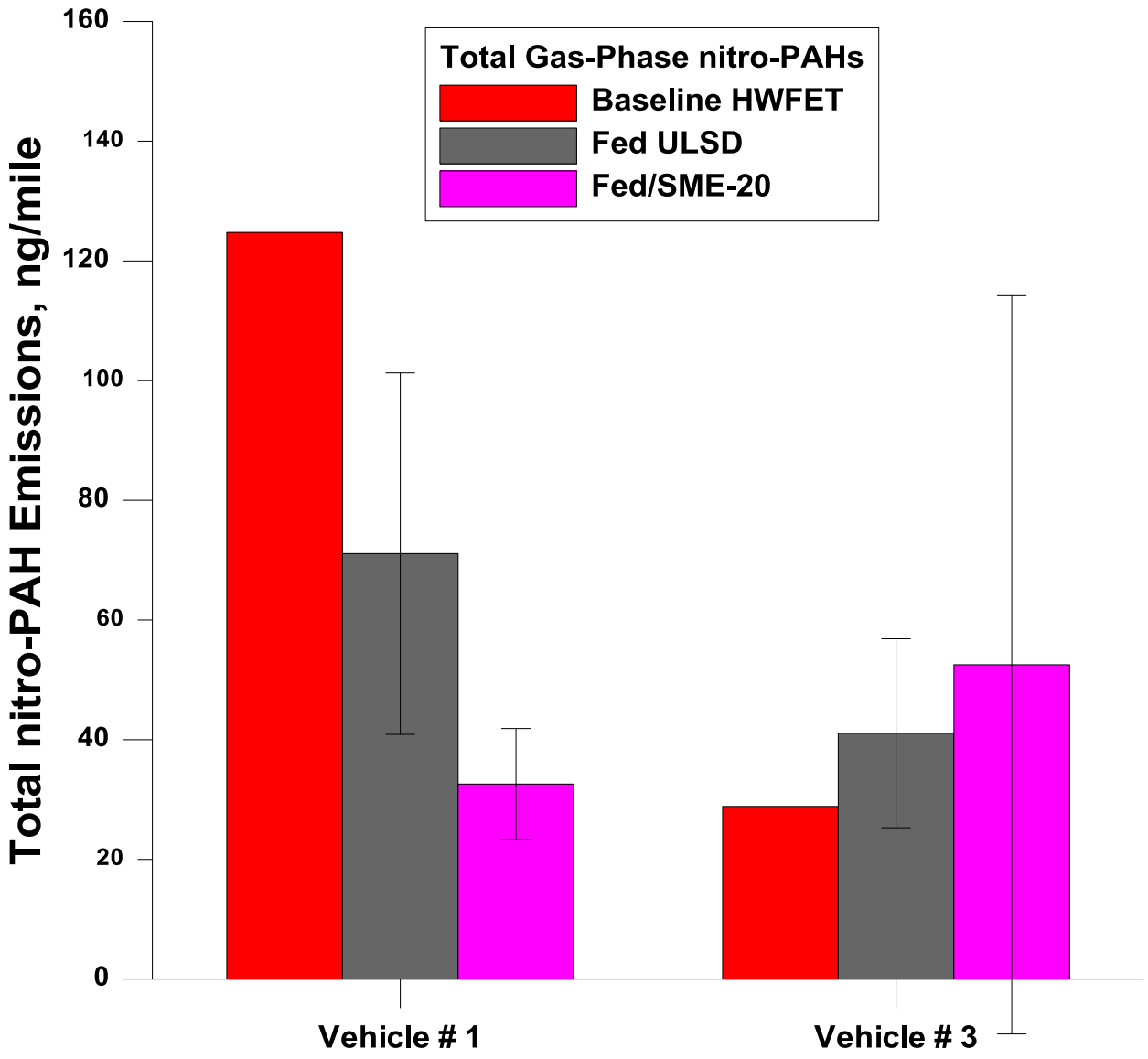


Figure 3-45: Total gas-phase nitro-PAH emissions during regeneration emissions testing over the HWFET cycle

Figure 3.46 displays the total particle-phase nitro-PAH emissions for both vehicles during DPF regeneration and baseline testing over the HWFET. Table D36 (see Appendix D) lists the individual particle-phase nitro-PAH species. Total particle-phase nitro-PAHs were found in considerably lower concentrations than the particle-phase compounds; the emission levels of Vehicle #3 were lower than those from Vehicle #1. The predominant species for both vehicles in the particle-phase were 3-nitrophenanthrene, 4-nitrophenanthrene, 1,8-dinitronaphthalene, and 1-nitropyrene. For both vehicles, particle-phase nitro-PAHs increased during regeneration testing compared to baseline testing. The particle-phase nitro-PAHs were lower for the biodiesel than Federal ULSD, but not at a statistically significant level given the experimental variability. Federal ULSD and biodiesel showed comparable emissions, within the experimental variability, for Vehicle #3.

Similar to gas-phase nitro-PAHs, formation of particle-phase species increased during regeneration testing, suggesting that several of these compounds can be formed de novo in the DPF via nitration reactions. Specifically, the compounds of 4-nitrophenanthrene, 3-nitrophenanthrene, and 9-nitrophenanthrene, detected at very low levels in baseline testing but at higher concentrations in regeneration testing, may have formed from a selective nitration of phenanthrene in the DPF. In addition, the relatively high concentration of 1-nitropyrene for both vehicles during regeneration testing could be due to the high NO_x emissions seen during the regeneration events that would cause nitration of some of the available pyrene, forming 1-nitropyrene.

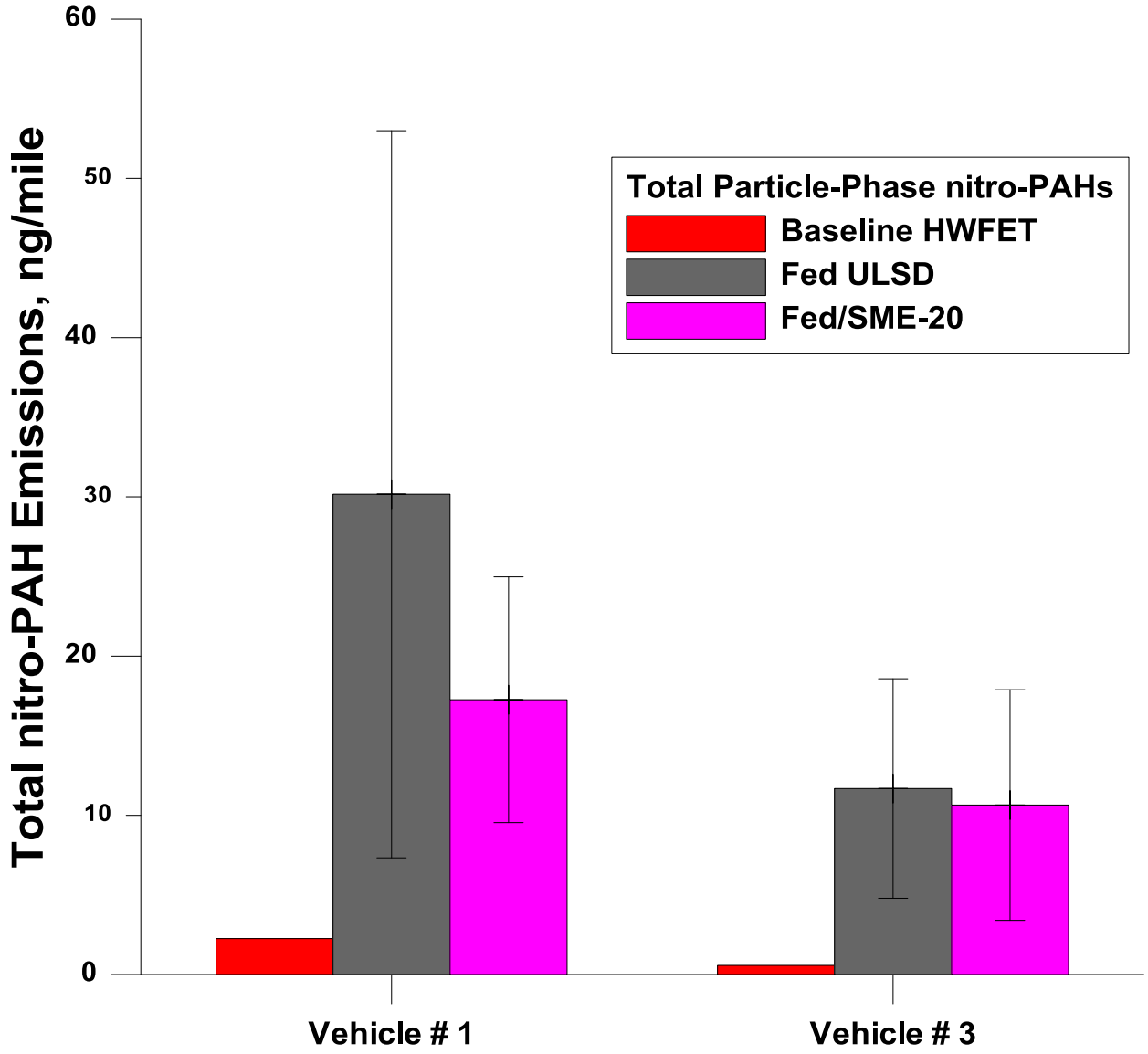


Figure 3-46: Total particle-phase nitro-PAH emissions during regeneration emissions testing over the HWFET cycle

EC and OC emissions for regeneration testing are shown in Figure 3.47 (a-b). For Vehicle #3, OC emissions increased by two to four times during DPF regeneration testing compared to baseline testing. Baseline testing on Vehicle #3 showed very low EC emissions, similar to FTP results. The DPF regeneration results show that much higher levels of EC are formed during DPF regeneration than during typical operation. The EC emissions rates were roughly twice those of corresponding OC emission rates for most combinations in the regeneration testing. The EC and OC emissions did not show strong fuel trends for the regeneration testing for either vehicle. Emissions for the Federal ULSD and the Fed/SME-20 were comparable in most cases within the experimental variability. Generally, for combustion, it is expected that the use of biodiesel would decrease the EC fraction due to the oxygen content in the methyl ester atoms, which inhibits the in-cylinder soot production both by disrupting the carbon chain development and by promoting oxidation. OC emissions depend on the physicochemical properties of the fuel. Unburned biodiesel is less volatile and hence more liable to nucleate and condense on smaller particles when the exhaust gas sample is cooled down in the tailpipe, resulting in increased OC emissions for biodiesel. As the vehicles do not show strong and consistent trends with respect to decreasing

EC and increasing OC with biodiesel, it appears the OC/EC trends with the aftertreatment are more complex than those related to basic combustion. Data from additional vehicles could provide more insight in this area.

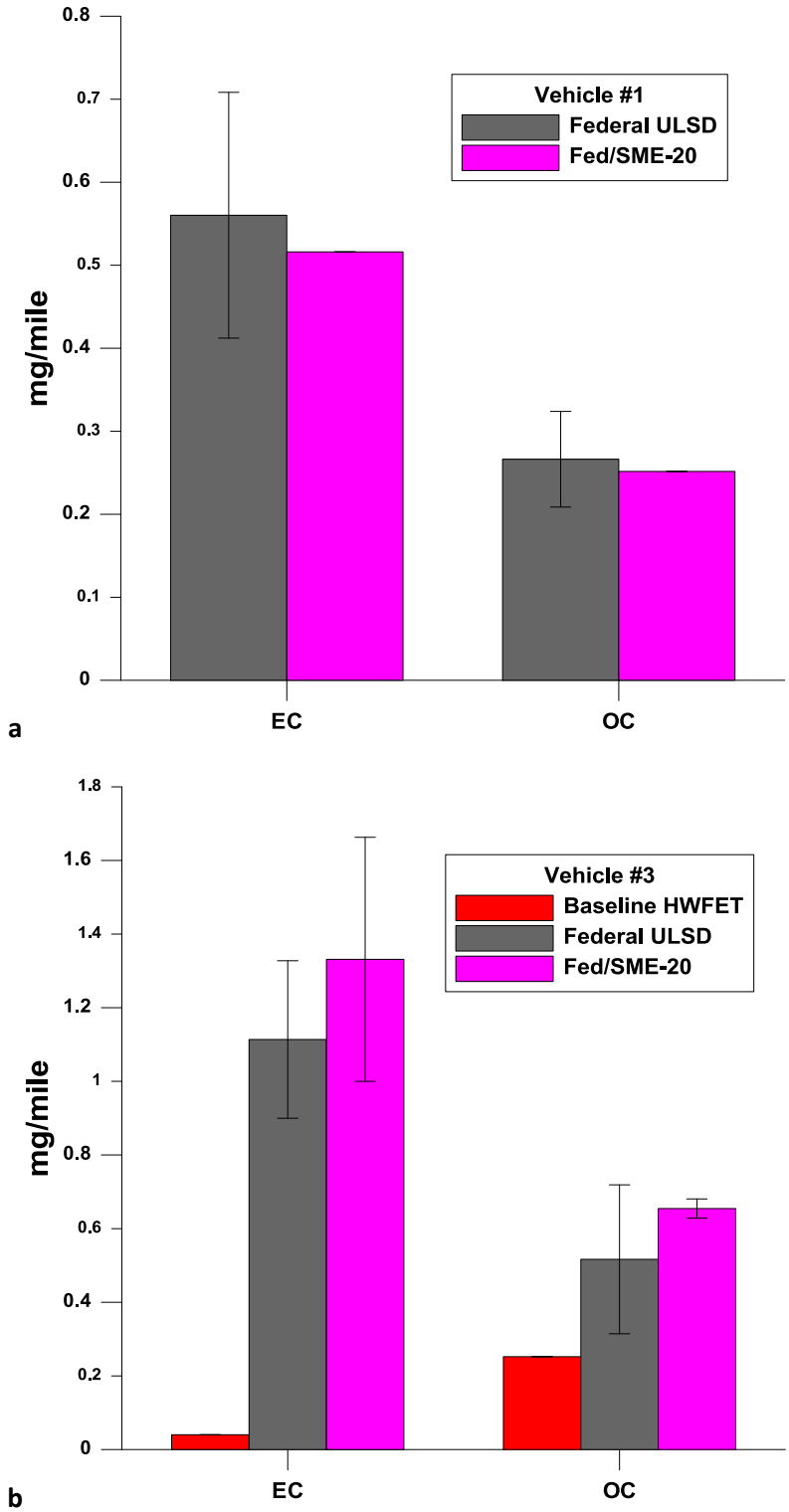


Figure 3-47 (a-b): EC/OC emissions for Vehicle #1 (a) and Vehicle #3 (b) during regeneration emission testing over the HWFET

Emissions of NH_3 are presented for Vehicle #1 during the baseline HWFET testing on Federal ULSD and the DPF regeneration testing on Federal ULSD and Fed/SME-20. For better representation of the results, the real-time traces of NH_3 and NO_x emissions over the HWFET

cycle are given to provide some insight on their formation mechanisms during the DPF regeneration event. Figure 3.48 (a-c) and Figure 3.49 (a-b) show the real-time NH_3 versus NO_x emissions, expressed in ppm, over the HWFET cycle for Vehicle #1. For the baseline HWFET testing, NH_3 emissions remained at very low concentrations throughout the entire cycle, while NO_x emissions showed some sharp peaks during the first 300 seconds of the cycle. Testing on the HWFET cycle was always done as a 'hot-start'; the vehicle was warmed up for 10-15 minutes at a steady state speed of 35-40 miles/hour followed by a soak period of approximately 15 minute prior to testing.

Figure 3.48 (b-c) presents the real-time NH_3 versus NO_x emissions during two regeneration emissions tests with the vehicle operated on Federal ULSD. For both tests, it can be observed that the DPF regeneration event started at approximately the same time, although the duration of the regeneration was somewhat different. Similar to the baseline HWFET testing, NO_x emissions appeared to peak during the first 150-200 seconds of the cycle, while NH_3 emissions were at very low levels prior to the start of the regeneration. During DPF regeneration, the opposite trend was observed with elevated NH_3 concentrations and low levels of NO_x emissions, suggesting that the SCR system enabled significant NO_x conversion during DPF regeneration. This result probably suggests that the operation of SCR is highly dependent on engine operating conditions when they affect the temperature of the aftertreatment system temperature and the exhaust, and the urea dosing strategy. It is interesting to note that elevated NH_3 concentrations (NH_3 slip) were seen during DPF regeneration, although it was expected that most of the NH_3 formed in excess of the amount needed to suppress NO_x emissions during regeneration would be combusted due to the high temperature in the DPF (greater than 550ºC). Figure 3.49 (a-b) shows the real-time NH_3 versus NO_x emissions during the regeneration emissions testing when the vehicle was operated on Fed/SME-20 blend. The NH_3 and NO_x emissions show similar behavior for the Fed/SME-20 blend to that seen for the Federal ULSD during regeneration, indicating that emissions during regeneration are primarily a function of the operation of the vehicle, and don't show strong fuel trends.

It is noteworthy that for both fuels, NH_3 concentrations were seen at elevated levels during the first stages of the DPF regeneration event, while NO_x emissions during this same period were at almost negligible levels. It appeared that as the regeneration evolved, NH_3 concentrations decreased somewhat along with corresponding increase in NO_x emissions. Spikes in NO_x emissions were also seen at various points throughout the regeneration, in some cases during accelerations but in other cases during decelerations, indicating that NO_x emissions during regeneration were likely to be related to a combination of factors in the operation of the engine and the aftertreatment system.

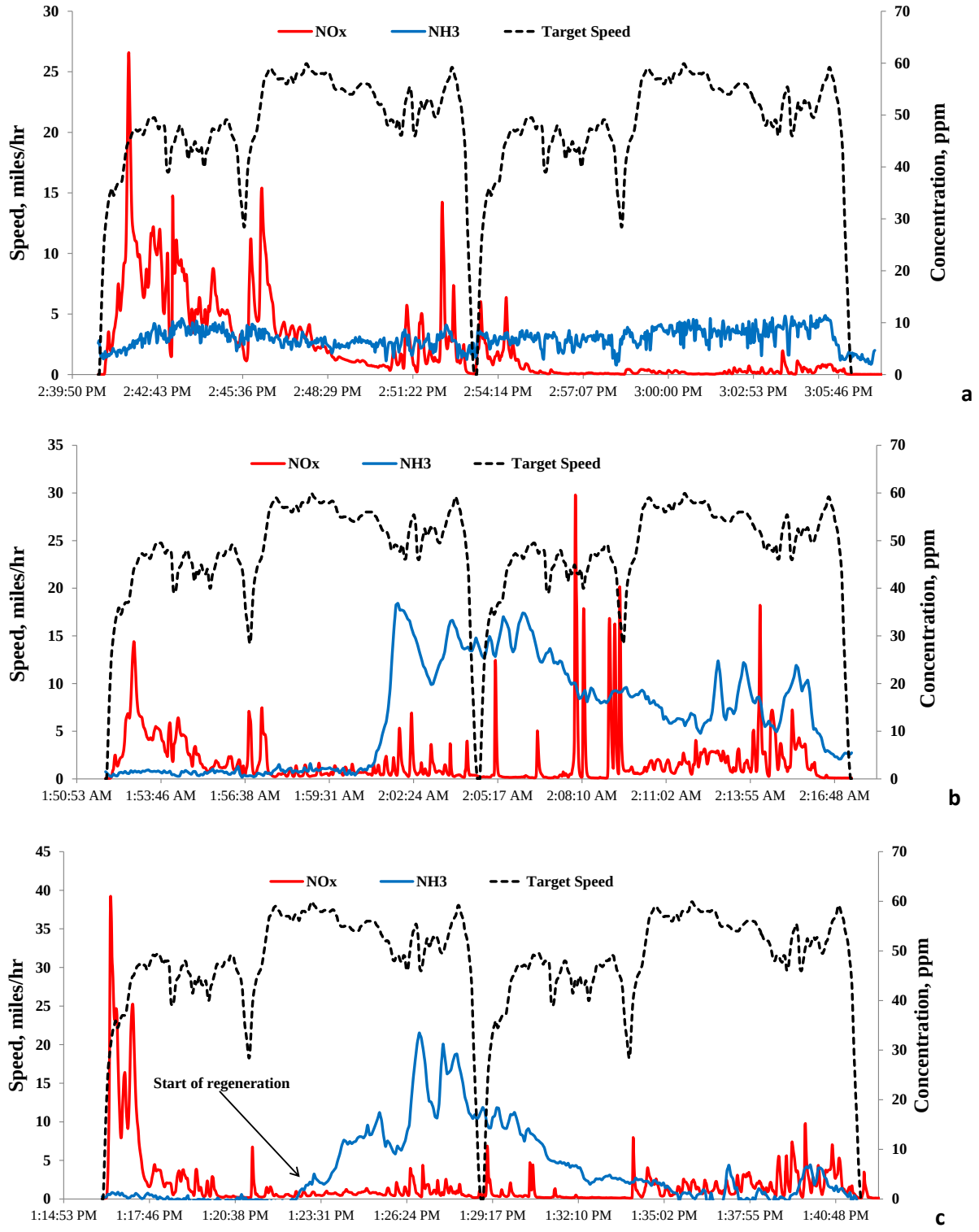


Figure 3-48 (a-c): Real-time NH_3 versus NO_x emissions for Vehicle #1 on Federal ULSD for the baseline HWFET testing (a), during regeneration emissions testing #1 (b) and regeneration emissions testing #2 (c)

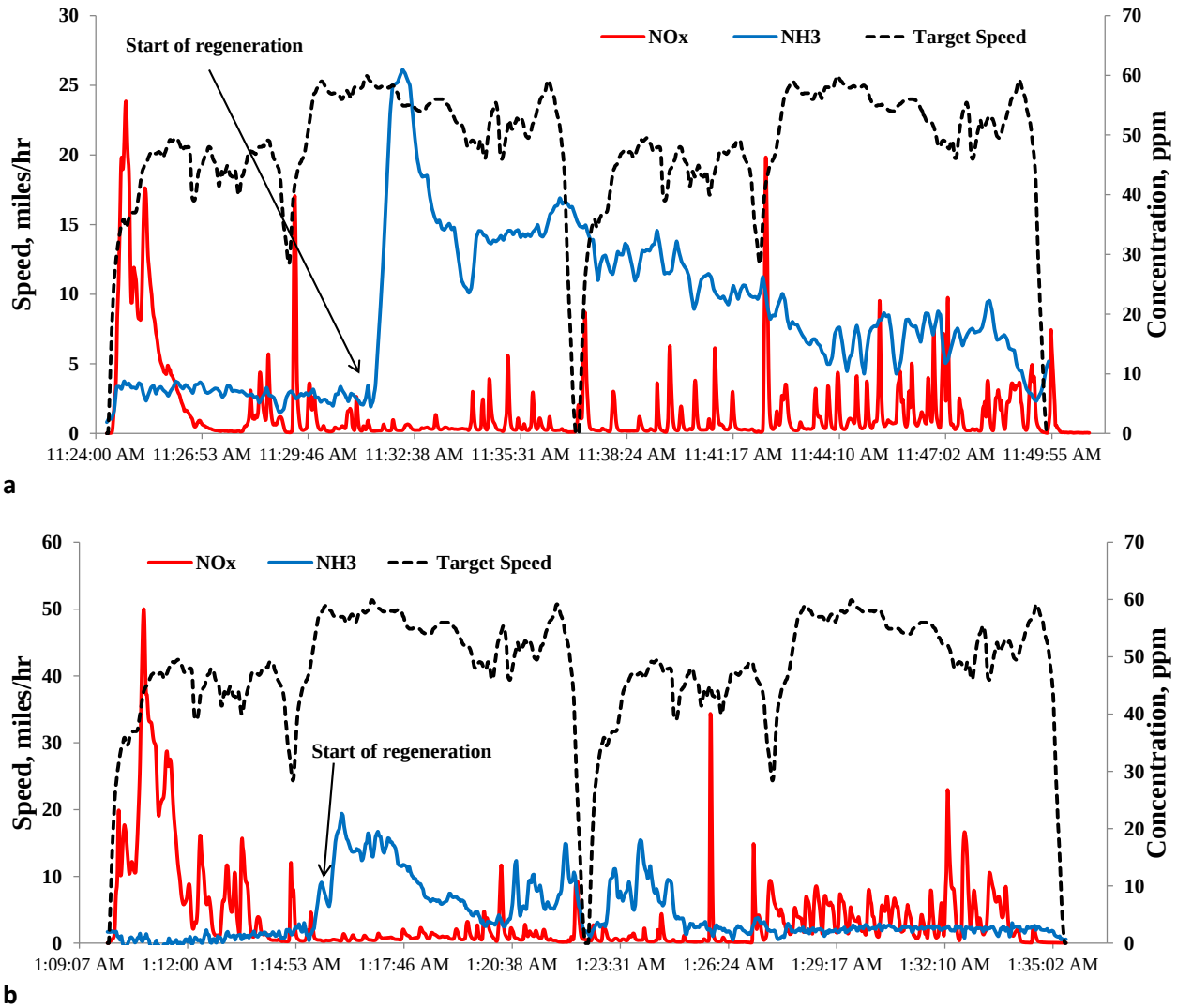


Figure 3-49 (a-b): Real-time NH_3 versus NO_x emissions for Vehicle #1 on Fed/SME-20 during regeneration emissions testing #1 (a) and regeneration emissions testing #2 (b) over the HWFET cycle

4. Summary

Currently, there is limited data on the emissions impacts of biofuels on light-duty diesel vehicles equipped with NO_x and PM emission control catalysts such as SCR and DPFs. The University of California, Riverside's College of Engineering-Center for Environmental Research and Technology (CE-CERT) and the Coordinating Research Council (CRC) have undertaken a comprehensive study, aimed specifically at understanding the effects of different biodiesel blends and renewable diesel blends on regulated and selected unregulated exhaust emissions from modern technology light-duty passenger cars and light-duty trucks. The resulting study was termed the 'CRC AVFL – 17b' program. This program was conducted in two phases. This report describes the analysis of the dataset collected in both phases of the AVFL-17b program. The effort encompassed emissions testing on eight light-duty diesel vehicles with seven different fuels over the Federal Test Procedure (FTP), including a Federal and California diesel, and five 20 vol% biodiesel and renewable diesel blends.

Test results for the fleet of eight vehicles are summarized below. They were tested for regulated emissions, fuel economy, particles, and toxic compounds. Statistical analyses on selected emission pollutants were performed using the Mixed procedure in PC/SAS from SAS Institute, Inc. For pollutants where the Mixed model showed that there were statistically significant differences between test fuels for FTP weighted composite or individual cycle phases, additional pairwise comparisons were performed using a least significant difference test to determine the specific fuel pairs that were statistically different. Results were classified as statistically significant for $p \leq 0.05$ and marginally statistically significant for $0.05 < p \leq 0.1$.

- Overall, THC emissions showed trends of lower emissions with the use of some biodiesel blends and CARB ULSD compared to Federal ULSD. The weighted THC emissions showed statistically significant differences between fuels, with CARB ULSD and CARB/WCO-20 blend showing decreases of 18% and 16%, respectively, compared to Federal ULSD. Statistically significant increases in weighted THC emissions of 19% and 17%, respectively, were found for Fed/SME-20 and Fed/WCO-20 blends compared to CARB ULSD.
- For the weighted NMHC emissions, CARB ULSD and Fed/HVO-20 showed statistically significant reductions of 28% and 24%, respectively, compared to Federal ULSD. Compared to CARB ULSD, the blends of Fed/SME-20 and Fed/WCO-20 also showed statistically significant increases in NMHC emissions of 48% and 49%, respectively. Similar to THC emissions, the blends of Fed/AFME-20, Fed/WCO-20, and CARB/WCO-20 showed statistically significant reductions compared to Fed/SME-20.
- For the weighted CO emissions, the results revealed a statistically significant decrease of 31% and a marginally statistically significant decrease of 18% for CARB ULSD and CARB/WCO-20, respectively, compared to Federal ULSD. Compared to CARB ULSD, the blends of Fed/SME-20, Fed/AFME-20, Fed/WCO-20, and Fed/HVO-20 showed statistically significant increases in CO emissions on the order of 52%, 22%, 40%, and 26%, respectively. The blends of Fed/AFME-20 and CARB/WCO-20 showed statistically significant decreases in CO emissions on the order of 19% and 22%, respectively, compared to Fed/SME-20, while a 17% decrease was also seen for Fed/HVO-20 compared to Fed/SME-20 at a marginally statistically significant level.
- No statistically significant fuel effects were seen neither for weighted NO_x nor NO_x from any individual phase of the FTP. For the subset of vehicles where NO and NO_2 were measured, NO_2 emissions were the predominant nitrogen oxide species of three vehicles, while NO was the predominant species for the other two vehicles. NO, NO_2, and the NO/NO_2 ratio did not show any statistically significant fuel effects. The lack of fuel

trends for the nitrogen oxides is largely a result of the presence of the SCR, which provides significant reductions that would likely negate any biodiesel fuel effects on these emissions. N_2O emissions did not show any statistically significant fuel effects for the same subset of vehicles.

- PM emission rates were below 3 mg/mi for all vehicles, ranging from approximately 0.18 to 2.65 mg/mi. PM mass emissions did not show any statistically significant differences between the test fuels. OC represented the predominant portion of the carbonaceous PM, with EC being at zero or near zero levels for most vehicles. The lack of fuel trends for the PM, OC, and EC is largely a result of the presence of the DPF, which provides significant reductions that would likely negate any biodiesel fuel effects on these emissions.
- An increasing trend in CO_2 emissions was observed with most of the biodiesel blends compared to the baseline Federal and CARB fuels. For the weighted CO_2 emissions, the results showed statistically significant increases of 1.9% for Fed/SME-20 and 2.3% for Fed/WCO-20 compared to Federal ULSD and of 1.7% for Fed/WCO-20 compared to CARB ULSD. The blend of Fed/WCO-20 showed a statistically significant increase in CO_2 emissions of 1.7% compared to Fed/AFME-20, whereas the blends of Fed/HVO-20 and CARB/WCO-20 showed statistically significant decreases of 2.5% and 1.7%, respectively, compared to Fed/WCO-20.
- For the weighted fuel economy, the results showed some strong effects for the Federal ULSD compared to CARB ULSD and the biofuel blends, but the CARB ULSD did not show strong effects compared to biodiesel blends. Compared to Federal ULSD, weighted fuel economy showed statistically significant decreases of 3.7%, 4.2%, 4.2%, 4.8%, 2.8%, and 5.7% for CARB ULSD, Fed/SME-20, Fed/AFME-20, Fed/WCO-20, Fed/HVO-20, and CARB/WCO-20. As expected, the CARB ULSD and the HVO blend showed smaller differences in fuel economy compared to the Federal ULSD. Compared to Federal ULSD, the heating values for Fed/SME-20, Fed/AFME-20, Fed/WCO-20, and CARB/WCO-20 were lower by 2.4%, 2.5%, 2.6%, and 1.3%, respectively, while the heating values for CARB ULSD and Fed/HVO-20 were higher by 1.2% and 0.8%, respectively. For CARB ULSD, the only statistically significant effect in weighted fuel economy was observed for CARB/WCO-20 blend, which showed a reduction of 2.1%. The blend of Fed/HVO-20 showed a statistically significant increase of 2.1% compared to Fed/WCO-20, while CARB/WCO-20 showed a statistically significant decrease of 3.0% compared to Fed/HVO-20.
- Particle number did not show any statistically significant fuel differences. The majority of particle number emissions were produced during cold start, during the first 200-300 seconds of the cycle.
- Particle size distributions were bimodal for most of the vehicles, showing particles in both the nucleation and accumulation modes, but some only showed unimodal distributions. Differences in particle size distributions between fuels were variable and not consistent from vehicle to vehicle.
- Formaldehyde and acetaldehyde were the predominant carbonyl compounds, although heavier carbonyl compounds were also identified. CARB ULSD showed a statistically significant decrease in formaldehyde emissions of 32% compared to Federal ULSD. Compared to CARB ULSD, the blends of Fed/SME-20, Fed/AFME-20, and Fed/WCO-20 showed statistically significant increases in formaldehyde emissions of 79%, 54%, and 75%, respectively. For acetaldehyde emissions, CARB ULSD showed a statistically significant decrease of 39% compared to Federal ULSD, whereas Fed/SME-20, Fed/WCO-20, and Fed/HVO-20 blends showed statistically significant increases of 79%, 72%, and 60%, respectively, compared to CARB ULSD. A marginally statistically significant increase of 53% for Fed/AFME-20 blend relative to CARB ULSD was also observed.

- Lower and medium molecular-weight compounds dominated the PAHs measured in the exhaust for all vehicle/fuel combinations, suggesting that these molecules were pyrolyzed from incomplete combustion of the fuel. Heavier PAHs were also found in the exhaust but in lesser amounts, suggesting that with increasing ring-number, PAHs were retained more efficiently in the DPF/DOC system. Total gas-phase PAH emissions were found in significantly higher concentrations than their corresponded particle-phase PAHs. The highest contributors to the gas-phase PAHs were mainly the two-membered ring compounds and their ethyl- and methyl-substitutes. The total PAH results for the biodiesel and the renewable diesel blends did not show clear trends, with some increases and some decreases in total PAH emissions compared to the baseline Federal and CARB ULSDs.
- The gas-phase nitro-PAHs were more abundant than particle-phase nitro-PAHs, with light weight compounds, such as nitronaphthalenes and methyl-substituted nitronaphthalenes, being dominant. The predominant species for the particle-phase nitro-PAHs were the nitrophenanthrenes and 1-nitropyrene. The biodiesel and the renewable diesel blends showed mixed results for gas- and particle-phase nitro-PAH emissions, with both increases and decreases. Statistically significant differences were only seen for gas-phase 1-nitronaphthalene emissions, with CARB ULSD and CARB/WCO-20 showing marginally statistically significant reductions of 87% and 89%, respectively, compared to Federal ULSD.
- Measureable NH_3 emissions were predominantly seen for Vehicle #1, which had average emissions ranging from 5.5 to 17.5 mg/mi, and Vehicle #2, which had average emissions ranging from 5.1 to 7.8 mg/mi. The NH_3 emissions for Vehicles #4 through #8 were near the background levels for most of the test matrix points, and generally had average NH_3 emissions of less than 1 mg/mi. In general, NH_3 emissions did not show any strong trends between the reference ULSDs and the biofuel blends for the fleet of eight vehicles.
- Emissions during regeneration showed increases compared to the baseline highway driving without regeneration. This tendency was seen for Vehicle #1 and for Vehicle #3 for the Fed/SME-20 blend but not as much for the Federal ULSD. Increases in emissions for some pollutants were seen for the biodiesel blend compared to the Federal ULSD, including THC, CH_4, particle number, black carbon, and formaldehyde for Vehicle #1, and THC, NMHC, CO, NO_x, CO_2, and formaldehyde for Vehicle #3. It was noteworthy that the use of biodiesel led to higher THC and CO emissions during the regeneration process, which could be an indication of poorer combustion efficiency relative to Federal ULSD. Particle size distributions during regeneration testing for both vehicles were dominated by the production of nucleation mode particles with peaks at around 10 nm in diameter. For other pollutants, biodiesel showed reductions in emissions relative to the Federal ULSD, including PAHs and gas-phase nitro-PAHs for Vehicle #1, and PM mass for Vehicle #3. Further analysis on the PAH results showed that biodiesel negatively influenced the formation of 2-ring PAH species during regeneration testing relative to Federal ULSD. It was also observed that certain nitrated species, which were practically below detection limits during baseline testing, increased with biodiesel relative to Federal ULSD during regeneration testing, suggesting that these species formed de novo in the DPF. The EC and OC emissions did not show strong fuel trends for the regeneration testing for either of the two vehicles tested, with the emissions for the Federal ULSD and the Fed/SME-20 being comparable in most cases within the experimental variability. During DPF regeneration, the concentrations of NH_3 were found at high levels (NH_3 slip) for both the Federal ULSD and the Fed/SME-20, while NO_x emissions were found at low concentrations, suggesting that the SCR system enabled significant NO_x conversion during DPF regeneration.

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Appendix A

Table A-1: Summary of statistical comparisons for different fuels

	Bag 1							Bag 2							Bag 3							Weighted						
NO_x	**LSM (g/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
	0.193	0.219	0.217	0.211	0.219	0.210	0.206	0.016	0.019	0.015	0.016	0.014	0.022	0.017	0.045	0.049	0.041	0.044	0.055	0.047	0.049	0.066	0.075	0.071	0.070	0.074	0.073	0.071
	Statistical Analysis																											
	NS							NS							NS							NS						
THC	**LSM (g/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
	0.109	0.087	0.115	0.095	0.108	0.097	0.094	0.018	0.015	0.017	0.015	0.016	0.015	0.014	0.019	0.016	0.016	0.017	0.016	0.018	0.017	0.040	0.032	0.039	0.034	0.038	0.035	0.033
	Statistical Analysis																											
	B 20% lower than A G 14% lower than A **C 31% higher than B** **E 24 % higher than B** **D 17% lower than C** **F 15% lower than C** **G 18% lower than C**							B 18% lower than A **G 23% lower than A** **G 20% lower than C**							NS							**B 18% lower than A** **G 16% lower than A** **C 19% higher than B** **E 17% higher than B** G 14% lower than C						
NMHC	**LSM (g/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
	0.067	0.048	0.077	0.058	0.071	0.055	0.055	0.004	0.002	0.002	0.002	0.002	0.001	0.002	0.004	0.003	0.003	0.003	0.004	0.002	0.003	0.018	0.013	0.019	0.014	0.019	0.013	0.014
	Statistical Analysis																											
	B 29% lower than A **F 18% lower than A** **G 18% lower than A** **C 60% higher than B** D 20% higher than B **E 50% higher than B** **D 25% lower than C** **F 28% lower than C** **G 29% lower than C** **E 24% higher than D** **F 23% lower than E** **G 24% lower than E**							NS							**F 47% lower than A**							**B 28% lower than A** **F 24% lower than A** G 20% lower than A **C 48% higher than B** **E 49% higher than B** **D 24% lower than C** **F 29% lower than C** **G 26% lower than C** **E 32% higher than C** **E 32% higher than D** **F 29% lower than E** **G 26% lower than E**						
CH_4	**LSM (g/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
	0.037	0.038	0.036	0.036	0.035	0.041	0.037	0.015	0.013	0.014	0.015	0.014	0.015	0.013	0.014	0.013	0.013	0.014	0.012	0.016	0.013	0.021	0.021	0.021	0.021	0.020	0.023	0.020
	Statistical Analysis																											

	Bag 1							Bag 2							Bag 3							Weighted						
	NS							G 13% lower than A F 14% higher than B G 13% lower than D **G 15% lower than F**							**F 22% higher than B** **F 21% higher than C** **F 27% higher than E** G 17% lower than F							**F 15% higher than E**						
CO	**LSM (g/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
	0.772	0.534	0.815	0.657	0.753	0.662	0.631	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.003	0.002	0.002	0.002	0.002	0.003	0.002	0.164	0.114	0.172	0.139	0.159	0.144	0.134
	Statistical Analysis																											
	B 31% lower than A **G 18% lower than A** **C 53% higher than B** **D 23% higher than B** **E 41% higher than B** **F 24% higher than B** **D 19% lower than C** **F 19% lower than C** **G 23% lower than C**							NS							NS							**B 31% lower than A** G 18% lower than A **C 52% higher than B** **D 22% higher than B** **E 40% higher than B** **F 26% higher than B** **D 19% lower than C** F 17% lower than C **G 22% lower than C**						
CO_2	**LSM (g/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
	529	531	533	528	538	523	525	452	456	462	457	464	453	458	421	422	430	423	431	420	423	460	462	469	463	470	459	462
	Statistical Analysis																											
	F 2.8% lower than E **G 2.4% lower than E**							**C 2.3% higher than A** **E 2.6% higher than A** **E 1.8% higher than B** **F 2.1% lower than C** **F 2.4% lower than E**							C 2.3% higher than A E 2.4% higher than A **F 2.4% lower than C** **F 2.4% lower than E**							**C 1.9% higher than A** **E 1.7% higher than A** **E 2.3% higher than B** **F 2.1% lower than C** **E 1.7% higher than D** **F 2.5% lower than E** **G 1.7% lower than E**						
FE	**LSM (miles/gallon)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
	0.044	0.046	0.046	0.046	0.046	0.045	0.047	0.038	0.040	0.040	0.040	0.040	0.039	0.041	0.035	0.036	0.037	0.037	0.037	0.036	0.037	0.039	0.040	0.040	0.040	0.041	0.040	0.041
	Statistical Analysis																											
	B 3.4% lower than A **C 3.3% lower than A** **D 3.8% lower than A** **E 4.3% lower than A** F 2.1% lower than A **G 4.6% lower than A** F 2.3% higher than E G 2.5% lower than F							**B 3.9% lower than A** **C 4.5% lower than A** **D 4.5% lower than A** **E 5.2% lower than A** **F 3.2% lower than A** **G 6.4% lower than A** **G 2.7 lower than B** F 2.1% higher than E **G 3.4% lower than F**							**B 3.6% lower than A** **C 4.7% lower than A** **D 3.9% lower than A** **E 4.6% lower than A** F 2.8 % lower than A **G 5.6% lower than A** G 2.9% lower than F							**B 3.7% lower than A** **C 4.2% lower than A** **D 4.2% lower than A** **E 4.6% lower than A** **F 2.8 % lower than A** **G 5.7% lower than A** **G 2.1% lower than B** **F 2.1% higher than E** **G 3.0% lower than F**						
PN	**LSM (particles/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G

	Bag 1							Bag 2							Bag 3							Weighted						
	3.27E+10	3.83E+10	4.79E+10	5.91E+10	3.20E+10	5.26E+10	5.21E+10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.52E+10	1.69E+10	1.95E+10	2.44E+10	1.33E+10	2.27E+10	2.31E+10
	Statistical Analysis																											
	NS							NA							NA							NS						
PM	**LSM (mg/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
																						0.871	0.917	0.815	0.731	0.776	0.913	1.139
	Statistical Analysis																											
																						NS						
Formaldehyde	**LSM (µg/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
																						4744	3227	5780	4986	5639	4384	4202
	Statistical Analysis																											
																						B 32% lower than A **C 79% higher than B** **D 54% higher than B** **E 75% higher than B**						
Acetaldehyde	**LSM (µg/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
																						1543	943	1684	1440	1622	1509	1408
	Statistical Analysis																											
																						B 39% lower than A **C 79% higher than B** **E 72% higher than B** **F 60% higher than B** D 53% higher than B						
EC	**LSM (mg/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
																						0.028	0.027	0.051	0.027	0.024	0.020	0.024
	Statistical Analysis																											
																						NS						
OC	**LSM (mg/mile)**																											
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
																						0.255	0.374	0.409	0.363	0.334	0.349	0.351
	Statistical Analysis																											
																						NS						

Where: A= Fed ULSD; B=CARB ULSD; C=Fed/SME-20; D=Fed/AFME-20; E=Fed/WCO-20; F=Fed/HVO-20; and G=CARB/WCO-20

Bold values are statistically significant $p \leq 0.05$; *Underlined values are marginally statistically significant* $0.05 < p \leq 0.1$

Appendix B

Table B1: Least square means for cold-start THC emissions

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	A	-2.2122	0.10946
fuel2	B	-2.4376	0.08737
fuel2	C	-2.1662	0.114612
fuel2	D	-2.3570	0.094704
fuel2	E	-2.2243	0.108143
fuel2	F	-2.3295	0.097344
fuel2	G	-2.3680	0.093668

Table B2: Multiple comparisons and p values for cold-start THC emissions

Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.2254	0.05236	124	4.30	<.0001	Tukey-Kramer	0.0007
fuel2	A	C	-0.04600	0.05307	124	-0.87	0.3878	Tukey-Kramer	0.9768
fuel2	A	D	0.1447	0.05433	124	2.66	0.0088	Tukey-Kramer	0.1165
fuel2	A	E	0.01208	0.05368	124	0.22	0.8224	Tukey-Kramer	1.0000
fuel2	A	F	0.1172	0.05352	124	2.19	0.0304	Tukey-Kramer	0.3084
fuel2	A	G	0.1558	0.05588	124	2.79	0.0062	Tukey-Kramer	0.0864
fuel2	B	C	-0.2714	0.05111	124	-5.31	<.0001	Tukey-Kramer	<.0001
fuel2	B	D	-0.08068	0.05243	124	-1.54	0.1264	Tukey-Kramer	0.7209
fuel2	B	E	-0.2133	0.05178	124	-4.12	<.0001	Tukey-Kramer	0.0013
fuel2	B	F	-0.1082	0.05171	124	-2.09	0.0385	Tukey-Kramer	0.3638
fuel2	B	G	-0.06964	0.05398	124	-1.29	0.1995	Tukey-Kramer	0.8554
fuel2	C	D	0.1907	0.05299	124	3.60	0.0005	Tukey-Kramer	0.0082
fuel2	C	E	0.05808	0.05219	124	1.11	0.2680	Tukey-Kramer	0.9232
fuel2	C	F	0.1632	0.05234	124	3.12	0.0023	Tukey-Kramer	0.0357
fuel2	C	G	0.2018	0.05454	124	3.70	0.0003	Tukey-Kramer	0.0058
fuel2	D	E	-0.1326	0.05367	124	-2.47	0.0148	Tukey-Kramer	0.1790

Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	D	F	-0.02750	0.05368	124	-0.51	0.6093	Tukey-Kramer	0.9986
fuel2	D	G	0.01105	0.05580	124	0.20	0.8434	Tukey-Kramer	1.0000
fuel2	E	F	0.1051	0.05295	124	1.99	0.0493	Tukey-Kramer	0.4290
fuel2	E	G	0.1437	0.05523	124	2.60	0.0104	Tukey-Kramer	0.1345
fuel2	F	G	0.03855	0.05523	124	0.70	0.4865	Tukey-Kramer	0.9925

Table B3: Least square means for hot-running THC emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-4.0333	0.017716
fuel2	B	-4.2296	0.014558
fuel2	C	-4.0797	0.016913
fuel2	D	-4.1733	0.015401
fuel2	E	-4.1166	0.0163
fuel2	F	-4.1999	0.014997
fuel2	G	-4.2989	0.013583

Table B4: Multiple comparisons and p values for hot-running THC emissions

Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.1963	0.06600	124	2.97	0.0035	Tukey-Kramer	0.0532
fuel2	A	C	0.04638	0.06690	124	0.69	0.4894	Tukey-Kramer	0.9928
fuel2	A	D	0.1400	0.06848	124	2.04	0.0430	Tukey-Kramer	0.3925
fuel2	A	E	0.08328	0.06766	124	1.23	0.2207	Tukey-Kramer	0.8808
fuel2	A	F	0.1666	0.06746	124	2.47	0.0149	Tukey-Kramer	0.1794
fuel2	A	G	0.2656	0.07044	124	3.77	0.0003	Tukey-Kramer	0.0046
fuel2	B	C	-0.1499	0.06442	124	-2.33	0.0216	Tukey-Kramer	0.2394
fuel2	B	D	-0.05633	0.06610	124	-0.85	0.3957	Tukey-Kramer	0.9787
fuel2	B	E	-0.1131	0.06527	124	-1.73	0.0858	Tukey-Kramer	0.5961
fuel2	B	F	-0.02968	0.06518	124	-0.46	0.6496	Tukey-Kramer	0.9993

Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	B	G	0.06924	0.06805	124	1.02	0.3109	Tukey-Kramer	0.9491
fuel2	C	D	0.09362	0.06680	124	1.40	0.1635	Tukey-Kramer	0.8001
fuel2	C	E	0.03690	0.06579	124	0.56	0.5759	Tukey-Kramer	0.9977
fuel2	C	F	0.1203	0.06598	124	1.82	0.0707	Tukey-Kramer	0.5354
fuel2	C	G	0.2192	0.06876	124	3.19	0.0018	Tukey-Kramer	0.0292
fuel2	D	E	-0.05672	0.06766	124	-0.84	0.4034	Tukey-Kramer	0.9804
fuel2	D	F	0.02665	0.06766	124	0.39	0.6944	Tukey-Kramer	0.9997
fuel2	D	G	0.1256	0.07034	124	1.79	0.0767	Tukey-Kramer	0.5605
fuel2	E	F	0.08337	0.06674	124	1.25	0.2140	Tukey-Kramer	0.8732
fuel2	E	G	0.1823	0.06962	124	2.62	0.0099	Tukey-Kramer	0.1294
fuel2	F	G	0.09892	0.06962	124	1.42	0.1579	Tukey-Kramer	0.7896

Table B5: Least squares means for weighted THC emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-3.2314	0.03950216
fuel2	B	-3.4285	0.03243556
fuel2	C	-3.2542	0.0386117
fuel2	D	-3.3670	0.03449296
fuel2	E	-3.2706	0.03798363
fuel2	F	-3.3386	0.0354866
fuel2	G	-3.3999	0.03337661

Table B6: Multiple comparisons and p values for weighted THC emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.1971	0.04821	124	4.09	<.0001	Tukey-Kramer	0.0015
fuel2	A	C	0.02274	0.04886	124	0.47	0.6425	Tukey-Kramer	0.9992
fuel2	A	D	0.1355	0.05002	124	2.71	0.0077	Tukey-Kramer	0.1046

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	E	0.03911	0.04942	124	0.79	0.4302	Tukey-Kramer	0.9854
fuel2	A	F	0.1071	0.04927	124	2.17	0.0316	Tukey-Kramer	0.3169
fuel2	A	G	0.1684	0.05145	124	3.27	0.0014	Tukey-Kramer	0.0227
fuel2	B	C	-0.1744	0.04705	124	-3.71	0.0003	Tukey-Kramer	0.0057
fuel2	B	D	-0.06158	0.04828	124	-1.28	0.2045	Tukey-Kramer	0.8618
fuel2	B	E	-0.1580	0.04767	124	-3.31	0.0012	Tukey-Kramer	0.0201
fuel2	B	F	-0.08995	0.04761	124	-1.89	0.0612	Tukey-Kramer	0.4913
fuel2	B	G	-0.02864	0.04970	124	-0.58	0.5654	Tukey-Kramer	0.9974
fuel2	C	D	0.1128	0.04879	124	2.31	0.0225	Tukey-Kramer	0.2470
fuel2	C	E	0.01637	0.04805	124	0.34	0.7339	Tukey-Kramer	0.9999
fuel2	C	F	0.08441	0.04819	124	1.75	0.0823	Tukey-Kramer	0.5830
fuel2	C	G	0.1457	0.05022	124	2.90	0.0044	Tukey-Kramer	0.0646
fuel2	D	E	-0.09640	0.04941	124	-1.95	0.0533	Tukey-Kramer	0.4512
fuel2	D	F	-0.02836	0.04942	124	-0.57	0.5671	Tukey-Kramer	0.9974
fuel2	D	G	0.03294	0.05137	124	0.64	0.5226	Tukey-Kramer	0.9953
fuel2	E	F	0.06803	0.04875	124	1.40	0.1653	Tukey-Kramer	0.8032
fuel2	E	G	0.1293	0.05085	124	2.54	0.0122	Tukey-Kramer	0.1531
fuel2	F	G	0.06130	0.05085	124	1.21	0.2303	Tukey-Kramer	0.8908

Table B7: Least square means for cold-start NMHC emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-2.7037	0.06695731
fuel2	B	-3.0413	0.04777274
fuel2	C	-2.5701	0.07652789
fuel2	D	-2.8553	0.05753856
fuel2	E	-2.6386	0.07146125
fuel2	F	-2.9041	0.05479809

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	G	-2.9079	0.05459025

Table B8: Multiple comparisons and p values for cold-start NMHC emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.3376	0.06281	124	5.37	<.0001	Tukey-Kramer	<.0001
fuel2	A	C	-0.1336	0.06366	124	-2.10	0.0379	Tukey-Kramer	0.3601
fuel2	A	D	0.1516	0.06517	124	2.33	0.0216	Tukey-Kramer	0.2399
fuel2	A	E	-0.06506	0.06439	124	-1.01	0.3143	Tukey-Kramer	0.9508
fuel2	A	F	0.2004	0.06420	124	3.12	0.0022	Tukey-Kramer	0.0354
fuel2	A	G	0.2042	0.06703	124	3.05	0.0028	Tukey-Kramer	0.0438
fuel2	B	C	-0.4712	0.06130	124	-7.69	<.0001	Tukey-Kramer	<.0001
fuel2	B	D	-0.1860	0.06290	124	-2.96	0.0037	Tukey-Kramer	0.0558
fuel2	B	E	-0.4026	0.06211	124	-6.48	<.0001	Tukey-Kramer	<.0001
fuel2	B	F	-0.1372	0.06203	124	-2.21	0.0288	Tukey-Kramer	0.2970
fuel2	B	G	-0.1334	0.06475	124	-2.06	0.0415	Tukey-Kramer	0.3829
fuel2	C	D	0.2852	0.06356	124	4.49	<.0001	Tukey-Kramer	0.0003
fuel2	C	E	0.06853	0.06261	124	1.09	0.2758	Tukey-Kramer	0.9286
fuel2	C	F	0.3340	0.06278	124	5.32	<.0001	Tukey-Kramer	<.0001
fuel2	C	G	0.3378	0.06543	124	5.16	<.0001	Tukey-Kramer	<.0001
fuel2	D	E	-0.2167	0.06438	124	-3.37	0.0010	Tukey-Kramer	0.0172
fuel2	D	F	0.04880	0.06438	124	0.76	0.4499	Tukey-Kramer	0.9884
fuel2	D	G	0.05258	0.06693	124	0.79	0.4336	Tukey-Kramer	0.9860
fuel2	E	F	0.2655	0.06351	124	4.18	<.0001	Tukey-Kramer	0.0011
fuel2	E	G	0.2692	0.06625	124	4.06	<.0001	Tukey-Kramer	0.0016
fuel2	F	G	0.003772	0.06625	124	0.06	0.9547	Tukey-Kramer	1.0000

Table B9: Least square means for hot-start NMHC emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-5.4478	0.00400577

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	B	-5.6448	0.00323586
fuel2	C	-5.6486	0.00322244
fuel2	D	-5.5824	0.00346352
fuel2	E	-5.4501	0.00399588
fuel2	F	-6.0286	0.00210886
fuel2	G	-5.6050	0.00337942

Table B10: Multiple comparisons and p values for hot-start NMHC emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.1970	0.1862	124	1.06	0.2923	Tukey-Kramer	0.9390
fuel2	A	C	0.2008	0.1888	124	1.06	0.2896	Tukey-Kramer	0.9375
fuel2	A	D	0.1346	0.1932	124	0.70	0.4875	Tukey-Kramer	0.9926
fuel2	A	E	0.002269	0.1909	124	0.01	0.9905	Tukey-Kramer	1.0000
fuel2	A	F	0.5808	0.1904	124	3.05	0.0028	Tukey-Kramer	0.0431
fuel2	A	G	0.1571	0.1988	124	0.79	0.4308	Tukey-Kramer	0.9855
fuel2	B	C	0.003790	0.1818	124	0.02	0.9834	Tukey-Kramer	1.0000
fuel2	B	D	-0.06240	0.1865	124	-0.33	0.7385	Tukey-Kramer	0.9999
fuel2	B	E	-0.1947	0.1842	124	-1.06	0.2925	Tukey-Kramer	0.9392
fuel2	B	F	0.3839	0.1839	124	2.09	0.0389	Tukey-Kramer	0.3669
fuel2	B	G	-0.03984	0.1920	124	-0.21	0.8360	Tukey-Kramer	1.0000
fuel2	C	D	-0.06619	0.1885	124	-0.35	0.7261	Tukey-Kramer	0.9998
fuel2	C	E	-0.1985	0.1856	124	-1.07	0.2871	Tukey-Kramer	0.9359
fuel2	C	F	0.3801	0.1862	124	2.04	0.0433	Tukey-Kramer	0.3943
fuel2	C	G	-0.04363	0.1940	124	-0.22	0.8224	Tukey-Kramer	1.0000
fuel2	D	E	-0.1323	0.1909	124	-0.69	0.4896	Tukey-Kramer	0.9928
fuel2	D	F	0.4463	0.1909	124	2.34	0.0210	Tukey-Kramer	0.2349
fuel2	D	G	0.02256	0.1985	124	0.11	0.9097	Tukey-Kramer	1.0000
fuel2	E	F	0.5785	0.1883	124	3.07	0.0026	Tukey-Kramer	0.0407

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	E	G	0.1549	0.1965	124	0.79	0.4321	Tukey-Kramer	0.9857
fuel2	F	G	-0.4237	0.1964	124	-2.16	0.0330	Tukey-Kramer	0.3267

Table B11: Least squares means for weighted NMHC emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-4.0379	0.01763447
fuel2	B	-4.3600	0.01277839
fuel2	C	-3.9681	0.01890933
fuel2	D	-4.2437	0.01435438
fuel2	E	-3.9641	0.01898512
fuel2	F	-4.3111	0.01341878
fuel2	G	-4.2659	0.01403923

Table B12: Multiple comparisons and p values for weighted NMHC emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.3221	0.07551	124	4.27	<.0001	Tukey-Kramer	0.0008
fuel2	A	C	-0.06984	0.07653	124	-0.91	0.3632	Tukey-Kramer	0.9699
fuel2	A	D	0.2058	0.07835	124	2.63	0.0097	Tukey-Kramer	0.1269
fuel2	A	E	-0.07376	0.07741	124	-0.95	0.3425	Tukey-Kramer	0.9628
fuel2	A	F	0.2732	0.07718	124	3.54	0.0006	Tukey-Kramer	0.0099
fuel2	A	G	0.2280	0.08059	124	2.83	0.0055	Tukey-Kramer	0.0778
fuel2	B	C	-0.3919	0.07370	124	-5.32	<.0001	Tukey-Kramer	<.0001
fuel2	B	D	-0.1163	0.07562	124	-1.54	0.1268	Tukey-Kramer	0.7218
fuel2	B	E	-0.3958	0.07468	124	-5.30	<.0001	Tukey-Kramer	<.0001
fuel2	B	F	-0.04888	0.07457	124	-0.66	0.5133	Tukey-Kramer	0.9947
fuel2	B	G	-0.09408	0.07785	124	-1.21	0.2291	Tukey-Kramer	0.8897

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	C	D	0.2757	0.07642	124	3.61	0.0004	Tukey-Kramer	0.0079
fuel2	C	E	-0.00392	0.07527	124	-0.05	0.9585	Tukey-Kramer	1.0000
fuel2	C	F	0.3430	0.07548	124	4.54	<.0001	Tukey-Kramer	0.0003
fuel2	C	G	0.2978	0.07866	124	3.79	0.0002	Tukey-Kramer	0.0043
fuel2	D	E	-0.2796	0.07740	124	-3.61	0.0004	Tukey-Kramer	0.0078
fuel2	D	F	0.06737	0.07741	124	0.87	0.3858	Tukey-Kramer	0.9763
fuel2	D	G	0.02217	0.08047	124	0.28	0.7834	Tukey-Kramer	1.0000
fuel2	E	F	0.3469	0.07636	124	4.54	<.0001	Tukey-Kramer	0.0003
fuel2	E	G	0.3017	0.07965	124	3.79	0.0002	Tukey-Kramer	0.0043
fuel2	F	G	-0.04520	0.07965	124	-0.57	0.5714	Tukey-Kramer	0.9976

Table B13: Least square means for hot-running CH_4 emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-4.2269	0.01459757
fuel2	B	-4.3245	0.01324017
fuel2	C	-4.2367	0.01445522
fuel2	D	-4.2247	0.01462972
fuel2	E	-4.2783	0.01386621
fuel2	F	-4.1976	0.01503161
fuel2	G	-4.3623	0.01274903

Table B14: Multiple comparisons and p values for hot-running CH_4 emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.09762	0.04481	124	2.18	0.0313	Tukey-Kramer	0.3147
fuel2	A	C	0.009819	0.04542	124	0.22	0.8292	Tukey-Kramer	1.0000
fuel2	A	D	-0.00222	0.04649	124	-0.05	0.9620	Tukey-Kramer	1.0000

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	E	0.05143	0.04594	124	1.12	0.2651	Tukey-Kramer	0.9210
fuel2	A	F	-0.02937	0.04580	124	-0.64	0.5226	Tukey-Kramer	0.9953
fuel2	A	G	0.1354	0.04783	124	2.83	0.0054	Tukey-Kramer	0.0774
fuel2	B	C	-0.08781	0.04374	124	-2.01	0.0469	Tukey-Kramer	0.4152
fuel2	B	D	-0.09984	0.04487	124	-2.22	0.0279	Tukey-Kramer	0.2899
fuel2	B	E	-0.04620	0.04432	124	-1.04	0.2992	Tukey-Kramer	0.9430
fuel2	B	F	-0.1270	0.04425	124	-2.87	0.0048	Tukey-Kramer	0.0701
fuel2	B	G	0.03777	0.04620	124	0.82	0.4152	Tukey-Kramer	0.9828
fuel2	C	D	-0.01204	0.04535	124	-0.27	0.7911	Tukey-Kramer	1.0000
fuel2	C	E	0.04161	0.04467	124	0.93	0.3534	Tukey-Kramer	0.9667
fuel2	C	F	-0.03919	0.04479	124	-0.87	0.3834	Tukey-Kramer	0.9757
fuel2	C	G	0.1256	0.04668	124	2.69	0.0081	Tukey-Kramer	0.1094
fuel2	D	E	0.05365	0.04593	124	1.17	0.2451	Tukey-Kramer	0.9048
fuel2	D	F	-0.02715	0.04594	124	-0.59	0.5556	Tukey-Kramer	0.9970
fuel2	D	G	0.1376	0.04775	124	2.88	0.0047	Tukey-Kramer	0.0679
fuel2	E	F	-0.08080	0.04531	124	-1.78	0.0770	Tukey-Kramer	0.5620
fuel2	E	G	0.08397	0.04727	124	1.78	0.0781	Tukey-Kramer	0.5664
fuel2	F	G	0.1648	0.04727	124	3.49	0.0007	Tukey-Kramer	0.0118

Table B15: Least square means for hot-start CH_4 emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-4.2663	0.01403361
fuel2	B	-4.3516	0.01288618
fuel2	C	-4.3429	0.01299878
fuel2	D	-4.2711	0.01396641
fuel2	E	-4.3909	0.01238957
fuel2	F	-4.1553	0.01568109

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	G	-4.3387	0.01305349

Table B16: Multiple comparisons and p values for hot-start CH_4 emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.08532	0.06041	124	1.41	0.1603	Tukey-Kramer	0.7942
fuel2	A	C	0.07657	0.06123	124	1.25	0.2134	Tukey-Kramer	0.8726
fuel2	A	D	0.004795	0.06267	124	0.08	0.9391	Tukey-Kramer	1.0000
fuel2	A	E	0.1246	0.06193	124	2.01	0.0464	Tukey-Kramer	0.4127
fuel2	A	F	-0.1110	0.06174	124	-1.80	0.0747	Tukey-Kramer	0.5523
fuel2	A	G	0.07235	0.06447	124	1.12	0.2639	Tukey-Kramer	0.9202
fuel2	B	C	-0.00875	0.05896	124	-0.15	0.8822	Tukey-Kramer	1.0000
fuel2	B	D	-0.08053	0.06049	124	-1.33	0.1856	Tukey-Kramer	0.8360
fuel2	B	E	0.03925	0.05974	124	0.66	0.5124	Tukey-Kramer	0.9946
fuel2	B	F	-0.1963	0.05966	124	-3.29	0.0013	Tukey-Kramer	0.0216
fuel2	B	G	-0.01297	0.06228	124	-0.21	0.8353	Tukey-Kramer	1.0000
fuel2	C	D	-0.07178	0.06113	124	-1.17	0.2426	Tukey-Kramer	0.9026
fuel2	C	E	0.04800	0.06021	124	0.80	0.4268	Tukey-Kramer	0.9849
fuel2	C	F	-0.1876	0.06038	124	-3.11	0.0024	Tukey-Kramer	0.0370
fuel2	C	G	-0.00422	0.06293	124	-0.07	0.9466	Tukey-Kramer	1.0000
fuel2	D	E	0.1198	0.06192	124	1.93	0.0553	Tukey-Kramer	0.4618
fuel2	D	F	-0.1158	0.06192	124	-1.87	0.0639	Tukey-Kramer	0.5042
fuel2	D	G	0.06756	0.06437	124	1.05	0.2960	Tukey-Kramer	0.9412
fuel2	E	F	-0.2356	0.06108	124	-3.86	0.0002	Tukey-Kramer	0.0034
fuel2	E	G	-0.05222	0.06372	124	-0.82	0.4140	Tukey-Kramer	0.9825
fuel2	F	G	0.1833	0.06372	124	2.88	0.0047	Tukey-Kramer	0.0687

Table B17: Least squares means for weighted CH_4 emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-3.8583	0.02110385

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	B	-3.8767	0.02071909
fuel2	C	-3.8863	0.02052113
fuel2	D	-3.8664	0.02093359
fuel2	E	-3.9115	0.02001046
fuel2	F	-3.7730	0.02298301
fuel2	G	-3.8898	0.02044944

Table B18: Multiple comparisons and p values for weighted CH_4 emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.01843	0.04258	124	0.43	0.6659	Tukey-Kramer	0.9995
fuel2	A	C	0.02804	0.04316	124	0.65	0.5172	Tukey-Kramer	0.9949
fuel2	A	D	0.008050	0.04418	124	0.18	0.8557	Tukey-Kramer	1.0000
fuel2	A	E	0.05319	0.04366	124	1.22	0.2254	Tukey-Kramer	0.8858
fuel2	A	F	-0.08532	0.04353	124	-1.96	0.0522	Tukey-Kramer	0.4452
fuel2	A	G	0.03149	0.04545	124	0.69	0.4897	Tukey-Kramer	0.9928
fuel2	B	C	0.009606	0.04156	124	0.23	0.8176	Tukey-Kramer	1.0000
fuel2	B	D	-0.01038	0.04265	124	-0.24	0.8081	Tukey-Kramer	1.0000
fuel2	B	E	0.03476	0.04211	124	0.83	0.4108	Tukey-Kramer	0.9819
fuel2	B	F	-0.1038	0.04206	124	-2.47	0.0150	Tukey-Kramer	0.1806
fuel2	B	G	0.01306	0.04390	124	0.30	0.7666	Tukey-Kramer	0.9999
fuel2	C	D	-0.01999	0.04310	124	-0.46	0.6436	Tukey-Kramer	0.9992
fuel2	C	E	0.02515	0.04245	124	0.59	0.5546	Tukey-Kramer	0.9969
fuel2	C	F	-0.1134	0.04257	124	-2.66	0.0088	Tukey-Kramer	0.1167
fuel2	C	G	0.003454	0.04436	124	0.08	0.9381	Tukey-Kramer	1.0000
fuel2	D	E	0.04514	0.04365	124	1.03	0.3031	Tukey-Kramer	0.9451

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	D	F	-0.09337	0.04365	124	-2.14	0.0344	Tukey-Kramer	0.3368
fuel2	D	G	0.02344	0.04538	124	0.52	0.6064	Tukey-Kramer	0.9986
fuel2	E	F	-0.1385	0.04306	124	-3.22	0.0017	Tukey-Kramer	0.0269
fuel2	E	G	-0.02170	0.04492	124	-0.48	0.6299	Tukey-Kramer	0.9990
fuel2	F	G	0.1168	0.04492	124	2.60	0.0104	Tukey-Kramer	0.1348

Table B19: Least squares means for cold-start CO emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-0.2589	0.77190021
fuel2	B	-0.6270	0.53419198
fuel2	C	-0.2050	0.81464732
fuel2	D	-0.4198	0.65717824
fuel2	E	-0.2835	0.75314312
fuel2	F	-0.4125	0.6619932
fuel2	G	-0.4601	0.63122052

Table B20: Multiple comparisons and p values for cold-start CO emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.3681	0.06208	124	5.93	<.0001	Tukey-Kramer	<.0001
fuel2	A	C	-0.05392	0.06292	124	-0.86	0.3931	Tukey-Kramer	0.9781
fuel2	A	D	0.1609	0.06441	124	2.50	0.0138	Tukey-Kramer	0.1692
fuel2	A	E	0.02465	0.06364	124	0.39	0.6991	Tukey-Kramer	0.9997
fuel2	A	F	0.1536	0.06345	124	2.42	0.0169	Tukey-Kramer	0.1989
fuel2	A	G	0.2013	0.06625	124	3.04	0.0029	Tukey-Kramer	0.0448
fuel2	B	C	-0.4221	0.06059	124	-6.97	<.0001	Tukey-Kramer	<.0001
fuel2	B	D	-0.2073	0.06216	124	-3.33	0.0011	Tukey-Kramer	0.0189

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	B	E	-0.3435	0.06139	124	-5.60	<.0001	Tukey-Kramer	<.0001
fuel2	B	F	-0.2146	0.06131	124	-3.50	0.0006	Tukey-Kramer	0.0113
fuel2	B	G	-0.1669	0.06400	124	-2.61	0.0102	Tukey-Kramer	0.1326
fuel2	C	D	0.2148	0.06282	124	3.42	0.0009	Tukey-Kramer	0.0146
fuel2	C	E	0.07857	0.06188	124	1.27	0.2065	Tukey-Kramer	0.8644
fuel2	C	F	0.2075	0.06205	124	3.34	0.0011	Tukey-Kramer	0.0183
fuel2	C	G	0.2552	0.06467	124	3.95	0.0001	Tukey-Kramer	0.0025
fuel2	D	E	-0.1362	0.06363	124	-2.14	0.0343	Tukey-Kramer	0.3358
fuel2	D	F	-0.00728	0.06363	124	-0.11	0.9091	Tukey-Kramer	1.0000
fuel2	D	G	0.04039	0.06615	124	0.61	0.5426	Tukey-Kramer	0.9964
fuel2	E	F	0.1289	0.06277	124	2.05	0.0421	Tukey-Kramer	0.3867
fuel2	E	G	0.1766	0.06548	124	2.70	0.0080	Tukey-Kramer	0.1077
fuel2	F	G	0.04767	0.06548	124	0.73	0.4680	Tukey-Kramer	0.9906

Table B21: Least squares means for weighted CO emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	-1.8096	0.16371961
fuel2	B	-2.1754	0.11356272
fuel2	C	-1.7589	0.17223422
fuel2	D	-1.9731	0.13902521
fuel2	E	-1.8403	0.15876979
fuel2	F	-1.9405	0.14363212
fuel2	G	-2.0068	0.13441813

Table B22: Multiple comparisons and p values for weighted CO emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.3658	0.06173	124	5.93	<.0001	Tukey-Kramer	<.0001
fuel2	A	C	-0.05072	0.06257	124	-0.81	0.4192	Tukey-Kramer	0.9835
fuel2	A	D	0.1635	0.06405	124	2.55	0.0119	Tukey-Kramer	0.1498
fuel2	A	E	0.03072	0.06328	124	0.49	0.6282	Tukey-Kramer	0.9990
fuel2	A	F	0.1309	0.06309	124	2.08	0.0401	Tukey-Kramer	0.3740
fuel2	A	G	0.1972	0.06588	124	2.99	0.0033	Tukey-Kramer	0.0505
fuel2	B	C	-0.4165	0.06025	124	-6.91	<.0001	Tukey-Kramer	<.0001
fuel2	B	D	-0.2022	0.06182	124	-3.27	0.0014	Tukey-Kramer	0.0228
fuel2	B	E	-0.3350	0.06105	124	-5.49	<.0001	Tukey-Kramer	<.0001
fuel2	B	F	-0.2348	0.06096	124	-3.85	0.0002	Tukey-Kramer	0.0034
fuel2	B	G	-0.1685	0.06364	124	-2.65	0.0091	Tukey-Kramer	0.1208
fuel2	C	D	0.2142	0.06247	124	3.43	0.0008	Tukey-Kramer	0.0141
fuel2	C	E	0.08144	0.06153	124	1.32	0.1881	Tukey-Kramer	0.8397
fuel2	C	F	0.1816	0.06171	124	2.94	0.0039	Tukey-Kramer	0.0578
fuel2	C	G	0.2479	0.06430	124	3.86	0.0002	Tukey-Kramer	0.0034
fuel2	D	E	-0.1328	0.06328	124	-2.10	0.0379	Tukey-Kramer	0.3598
fuel2	D	F	-0.03261	0.06328	124	-0.52	0.6072	Tukey-Kramer	0.9986
fuel2	D	G	0.03370	0.06578	124	0.51	0.6093	Tukey-Kramer	0.9986
fuel2	E	F	0.1002	0.06242	124	1.61	0.1110	Tukey-Kramer	0.6792
fuel2	E	G	0.1665	0.06511	124	2.56	0.0118	Tukey-Kramer	0.1485
fuel2	F	G	0.06631	0.06511	124	1.02	0.3105	Tukey-Kramer	0.9489

Table B23: Least squares means for cold-start CO_2 emissions

Least Squares Means			
Effect	fuel2	Estimate	Standard Error
fuel2	A	6.2713	529.164845
fuel2	B	6.2741	530.648583
fuel2	C	6.2785	532.988581
fuel2	D	6.2683	527.57973
fuel2	E	6.2879	538.022295

Least Squares Means			
Effect	fuel2	Estimate	Standard Error
fuel2	F	6.2593	522.852815
fuel2	G	6.2633	524.948415

Table B24: Multiple comparisons and p values for cold-start CO_2 emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	-0.00278	0.007498	124	-0.37	0.7119	Tukey-Kramer	0.9998
fuel2	A	C	-0.00718	0.007600	124	-0.94	0.3468	Tukey-Kramer	0.9644
fuel2	A	D	0.003013	0.007780	124	0.39	0.6992	Tukey-Kramer	0.9997
fuel2	A	E	-0.01662	0.007687	124	-2.16	0.0326	Tukey-Kramer	0.3241
fuel2	A	F	0.01200	0.007664	124	1.57	0.1200	Tukey-Kramer	0.7042
fuel2	A	G	0.008029	0.008002	124	1.00	0.3177	Tukey-Kramer	0.9524
fuel2	B	C	-0.00440	0.007318	124	-0.60	0.5486	Tukey-Kramer	0.9967
fuel2	B	D	0.005788	0.007509	124	0.77	0.4423	Tukey-Kramer	0.9873
fuel2	B	E	-0.01384	0.007415	124	-1.87	0.0643	Tukey-Kramer	0.5064
fuel2	B	F	0.01477	0.007405	124	2.00	0.0482	Tukey-Kramer	0.4229
fuel2	B	G	0.01080	0.007730	124	1.40	0.1647	Tukey-Kramer	0.8021
fuel2	C	D	0.01019	0.007588	124	1.34	0.1818	Tukey-Kramer	0.8303
fuel2	C	E	-0.00944	0.007474	124	-1.26	0.2090	Tukey-Kramer	0.8674
fuel2	C	F	0.01918	0.007495	124	2.56	0.0117	Tukey-Kramer	0.1481
fuel2	C	G	0.01521	0.007811	124	1.95	0.0538	Tukey-Kramer	0.4538
fuel2	D	E	-0.01963	0.007686	124	-2.55	0.0119	Tukey-Kramer	0.1497
fuel2	D	F	0.008987	0.007686	124	1.17	0.2446	Tukey-Kramer	0.9043
fuel2	D	G	0.005016	0.007990	124	0.63	0.5313	Tukey-Kramer	0.9958
fuel2	E	F	0.02861	0.007582	124	3.77	0.0002	Tukey-Kramer	0.0045
fuel2	E	G	0.02464	0.007909	124	3.12	0.0023	Tukey-Kramer	0.0360
fuel2	F	G	-0.00397	0.007909	124	-0.50	0.6166	Tukey-Kramer	0.9988

Table B25: Least squares means for hot-running CO_2 emissions

Least Squares Means			
Effect	fuel2	Estimate	Standard Error

Least Squares Means			
Effect	fuel2	Estimate	Standard Error
fuel2	A	6.1136	451.962856
fuel2	B	6.1217	455.638622
fuel2	C	6.1365	462.432222
fuel2	D	6.1254	457.327608
fuel2	E	6.1395	463.821602
fuel2	F	6.1149	452.55079
fuel2	G	6.1262	457.693616

Table B26: Multiple comparisons and p values for hot-running CO_2 emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	-0.00809	0.005618	124	-1.44	0.1521	Tukey-Kramer	0.7785
fuel2	A	C	-0.02287	0.005694	124	-4.02	0.0001	Tukey-Kramer	0.0019
fuel2	A	D	-0.01180	0.005829	124	-2.02	0.0451	Tukey-Kramer	0.4052
fuel2	A	E	-0.02591	0.005759	124	-4.50	<.0001	Tukey-Kramer	0.0003
fuel2	A	F	-0.00131	0.005742	124	-0.23	0.8199	Tukey-Kramer	1.0000
fuel2	A	G	-0.01258	0.005996	124	-2.10	0.0380	Tukey-Kramer	0.3605
fuel2	B	C	-0.01478	0.005483	124	-2.70	0.0080	Tukey-Kramer	0.1081
fuel2	B	D	-0.00370	0.005626	124	-0.66	0.5118	Tukey-Kramer	0.9945
fuel2	B	E	-0.01782	0.005556	124	-3.21	0.0017	Tukey-Kramer	0.0276
fuel2	B	F	0.006784	0.005548	124	1.22	0.2237	Tukey-Kramer	0.8840
fuel2	B	G	-0.00448	0.005792	124	-0.77	0.4404	Tukey-Kramer	0.9870
fuel2	C	D	0.01108	0.005685	124	1.95	0.0536	Tukey-Kramer	0.4528
fuel2	C	E	-0.00304	0.005600	124	-0.54	0.5881	Tukey-Kramer	0.9981
fuel2	C	F	0.02156	0.005616	124	3.84	0.0002	Tukey-Kramer	0.0036
fuel2	C	G	0.01030	0.005852	124	1.76	0.0810	Tukey-Kramer	0.5779
fuel2	D	E	-0.01412	0.005758	124	-2.45	0.0156	Tukey-Kramer	0.1865
fuel2	D	F	0.01049	0.005759	124	1.82	0.0710	Tukey-Kramer	0.5367

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	D	G	-0.00078	0.005986	124	-0.13	0.8963	Tukey-Kramer	1.0000
fuel2	E	F	0.02460	0.005681	124	4.33	<.0001	Tukey-Kramer	0.0006
fuel2	E	G	0.01334	0.005926	124	2.25	0.0262	Tukey-Kramer	0.2768
fuel2	F	G	-0.01127	0.005926	124	-1.90	0.0596	Tukey-Kramer	0.4833

Table B27: Least squares means for hot-start CO_2 emissions

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	6.0420	420.733661
fuel2	B	6.0454	422.16659
fuel2	C	6.0649	430.479628
fuel2	D	6.0476	423.096379
fuel2	E	6.0653	430.651854
fuel2	F	6.0406	420.145046
fuel2	G	6.0484	423.434992

Table B28: Multiple comparisons and p values for hot-start CO_2 emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	-0.00339	0.007635	124	-0.44	0.6581	Tukey-Kramer	0.9994
fuel2	A	C	-0.02294	0.007739	124	-2.96	0.0036	Tukey-Kramer	0.0546
fuel2	A	D	-0.00556	0.007922	124	-0.70	0.4841	Tukey-Kramer	0.9923
fuel2	A	E	-0.02329	0.007827	124	-2.98	0.0035	Tukey-Kramer	0.0530
fuel2	A	F	0.001449	0.007804	124	0.19	0.8530	Tukey-Kramer	1.0000
fuel2	A	G	-0.00641	0.008149	124	-0.79	0.4328	Tukey-Kramer	0.9858
fuel2	B	C	-0.01955	0.007452	124	-2.62	0.0098	Tukey-Kramer	0.1278
fuel2	B	D	-0.00217	0.007646	124	-0.28	0.7767	Tukey-Kramer	1.0000
fuel2	B	E	-0.01991	0.007551	124	-2.64	0.0094	Tukey-Kramer	0.1241

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	B	F	0.004836	0.007540	124	0.64	0.5225	Tukey-Kramer	0.9953
fuel2	B	G	-0.00303	0.007872	124	-0.38	0.7013	Tukey-Kramer	0.9997
fuel2	C	D	0.01738	0.007727	124	2.25	0.0263	Tukey-Kramer	0.2774
fuel2	C	E	-0.00035	0.007611	124	-0.05	0.9630	Tukey-Kramer	1.0000
fuel2	C	F	0.02439	0.007632	124	3.20	0.0018	Tukey-Kramer	0.0286
fuel2	C	G	0.01653	0.007954	124	2.08	0.0398	Tukey-Kramer	0.3722
fuel2	D	E	-0.01773	0.007826	124	-2.27	0.0252	Tukey-Kramer	0.2690
fuel2	D	F	0.007009	0.007827	124	0.90	0.3722	Tukey-Kramer	0.9726
fuel2	D	G	-0.00085	0.008136	124	-0.10	0.9167	Tukey-Kramer	1.0000
fuel2	E	F	0.02474	0.007721	124	3.20	0.0017	Tukey-Kramer	0.0278
fuel2	E	G	0.01688	0.008054	124	2.10	0.0381	Tukey-Kramer	0.3615
fuel2	F	G	-0.00786	0.008054	124	-0.98	0.3308	Tukey-Kramer	0.9582

Table B29: Least squares means for weighted CO_2 emissions

Least Squares Means			
Effect	fuel2	Estimate	Standard Error
fuel2	A	6.1308	459.803857
fuel2	B	6.1364	462.385981
fuel2	C	6.1497	468.576793
fuel2	D	6.1371	462.709765
fuel2	E	6.1537	470.454853
fuel2	F	6.1280	458.518207
fuel2	G	6.1365	462.432222

Table B30: Multiple comparisons and p values for weighted CO_2 emissions

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	-0.00568	0.005135	124	-1.11	0.2710	Tukey-Kramer	0.9253

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	C	-0.01897	0.005205	124	-3.64	0.0004	Tukey-Kramer	0.0070
fuel2	A	D	-0.00633	0.005328	124	-1.19	0.2369	Tukey-Kramer	0.8973
fuel2	A	E	-0.02291	0.005264	124	-4.35	<.0001	Tukey-Kramer	0.0005
fuel2	A	F	0.002734	0.005249	124	0.52	0.6034	Tukey-Kramer	0.9985
fuel2	A	G	-0.00575	0.005481	124	-1.05	0.2959	Tukey-Kramer	0.9411
fuel2	B	C	-0.01329	0.005012	124	-2.65	0.0091	Tukey-Kramer	0.1200
fuel2	B	D	-0.00065	0.005142	124	-0.13	0.8989	Tukey-Kramer	1.0000
fuel2	B	E	-0.01723	0.005078	124	-3.39	0.0009	Tukey-Kramer	0.0157
fuel2	B	F	0.008411	0.005071	124	1.66	0.0997	Tukey-Kramer	0.6446
fuel2	B	G	-0.00008	0.005294	124	-0.01	0.9887	Tukey-Kramer	1.0000
fuel2	C	D	0.01263	0.005197	124	2.43	0.0165	Tukey-Kramer	0.1947
fuel2	C	E	-0.00395	0.005119	124	-0.77	0.4422	Tukey-Kramer	0.9873
fuel2	C	F	0.02170	0.005133	124	4.23	<.0001	Tukey-Kramer	0.0009
fuel2	C	G	0.01321	0.005349	124	2.47	0.0149	Tukey-Kramer	0.1795
fuel2	D	E	-0.01658	0.005264	124	-3.15	0.0020	Tukey-Kramer	0.0327
fuel2	D	F	0.009066	0.005264	124	1.72	0.0875	Tukey-Kramer	0.6026
fuel2	D	G	0.000579	0.005472	124	0.11	0.9159	Tukey-Kramer	1.0000
fuel2	E	F	0.02565	0.005193	124	4.94	<.0001	Tukey-Kramer	<.0001
fuel2	E	G	0.01716	0.005417	124	3.17	0.0019	Tukey-Kramer	0.0310
fuel2	F	G	-0.00849	0.005417	124	-1.57	0.1197	Tukey-Kramer	0.7036

Table B31: Least squares means for cold-start fuel economy

Least Squares Means		
Effect	fuel2	Estimate
fuel2	A	22.5265
fuel2	B	21.7664
fuel2	C	21.7912
fuel2	D	21.6802
fuel2	E	21.5562
fuel2	F	22.0430
fuel2	G	21.4915

Table B32: Multiple comparisons and p values for cold-start fuel economy

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.7601	0.1648	124	4.61	<.0001	Tukey-Kramer	0.0002
fuel2	A	C	0.7353	0.1671	124	4.40	<.0001	Tukey-Kramer	0.0004
fuel2	A	D	0.8463	0.1710	124	4.95	<.0001	Tukey-Kramer	<.0001
fuel2	A	E	0.9703	0.1690	124	5.74	<.0001	Tukey-Kramer	<.0001
fuel2	A	F	0.4836	0.1685	124	2.87	0.0048	Tukey-Kramer	0.0700
fuel2	A	G	1.0350	0.1759	124	5.88	<.0001	Tukey-Kramer	<.0001
fuel2	B	C	-0.02476	0.1609	124	-0.15	0.8779	Tukey-Kramer	1.0000
fuel2	B	D	0.08621	0.1651	124	0.52	0.6024	Tukey-Kramer	0.9985
fuel2	B	E	0.2102	0.1630	124	1.29	0.1996	Tukey-Kramer	0.8555
fuel2	B	F	-0.2765	0.1628	124	-1.70	0.0919	Tukey-Kramer	0.6181
fuel2	B	G	0.2749	0.1699	124	1.62	0.1082	Tukey-Kramer	0.6712
fuel2	C	D	0.1110	0.1668	124	0.67	0.5071	Tukey-Kramer	0.9942
fuel2	C	E	0.2350	0.1643	124	1.43	0.1552	Tukey-Kramer	0.7845
fuel2	C	F	-0.2518	0.1648	124	-1.53	0.1290	Tukey-Kramer	0.7275
fuel2	C	G	0.2997	0.1717	124	1.75	0.0834	Tukey-Kramer	0.5871
fuel2	D	E	0.1240	0.1689	124	0.73	0.4644	Tukey-Kramer	0.9902
fuel2	D	F	-0.3627	0.1690	124	-2.15	0.0337	Tukey-Kramer	0.3323
fuel2	D	G	0.1887	0.1756	124	1.07	0.2848	Tukey-Kramer	0.9345
fuel2	E	F	-0.4867	0.1667	124	-2.92	0.0042	Tukey-Kramer	0.0614
fuel2	E	G	0.06470	0.1739	124	0.37	0.7104	Tukey-Kramer	0.9998
fuel2	F	G	0.5514	0.1739	124	3.17	0.0019	Tukey-Kramer	0.0306

Table B33: Least squares means for hot-running fuel economy

Least Squares Means		
Effect	fuel2	Estimate
fuel2	A	26.3148
fuel2	B	25.2998
fuel2	C	25.1340
fuel2	D	25.1191
fuel2	E	24.9499
fuel2	F	25.4745

Least Squares Means		
Effect	fuel2	Estimate
fuel2	G	24.6283

Table B34: Multiple comparisons and p values for hot-running fuel economy

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	1.0150	0.1785	124	5.69	<.0001	Tukey-Kramer	<.0001
fuel2	A	C	1.1808	0.1810	124	6.53	<.0001	Tukey-Kramer	<.0001
fuel2	A	D	1.1957	0.1852	124	6.46	<.0001	Tukey-Kramer	<.0001
fuel2	A	E	1.3649	0.1830	124	7.46	<.0001	Tukey-Kramer	<.0001
fuel2	A	F	0.8403	0.1825	124	4.60	<.0001	Tukey-Kramer	0.0002
fuel2	A	G	1.6865	0.1905	124	8.85	<.0001	Tukey-Kramer	<.0001
fuel2	B	C	0.1658	0.1743	124	0.95	0.3431	Tukey-Kramer	0.9631
fuel2	B	D	0.1808	0.1788	124	1.01	0.3139	Tukey-Kramer	0.9506
fuel2	B	E	0.3499	0.1766	124	1.98	0.0497	Tukey-Kramer	0.4314
fuel2	B	F	-0.1747	0.1763	124	-0.99	0.3238	Tukey-Kramer	0.9552
fuel2	B	G	0.6716	0.1841	124	3.65	0.0004	Tukey-Kramer	0.0069
fuel2	C	D	0.01493	0.1807	124	0.08	0.9343	Tukey-Kramer	1.0000
fuel2	C	E	0.1841	0.1780	124	1.03	0.3030	Tukey-Kramer	0.9450
fuel2	C	F	-0.3405	0.1785	124	-1.91	0.0587	Tukey-Kramer	0.4790
fuel2	C	G	0.5057	0.1860	124	2.72	0.0075	Tukey-Kramer	0.1021
fuel2	D	E	0.1691	0.1830	124	0.92	0.3572	Tukey-Kramer	0.9680
fuel2	D	F	-0.3554	0.1830	124	-1.94	0.0544	Tukey-Kramer	0.4568
fuel2	D	G	0.4908	0.1902	124	2.58	0.0111	Tukey-Kramer	0.1413
fuel2	E	F	-0.5246	0.1805	124	-2.91	0.0043	Tukey-Kramer	0.0638
fuel2	E	G	0.3217	0.1883	124	1.71	0.0901	Tukey-Kramer	0.6120
fuel2	F	G	0.8462	0.1883	124	4.49	<.0001	Tukey-Kramer	0.0003

Table B35: Least squares means for hot-start fuel economy

Least Squares Means		
Effect	fuel2	Estimate
fuel2	A	28.4521
fuel2	B	27.4355
fuel2	C	27.1274

Least Squares Means		
Effect	fuel2	Estimate
fuel2	D	27.3353
fuel2	E	27.1310
fuel2	F	27.6558
fuel2	G	26.8505

Table B36: Multiple comparisons and p values for hot-start fuel economy

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	1.0166	0.2609	124	3.90	0.0002	Tukey-Kramer	0.0030
fuel2	A	C	1.3247	0.2644	124	5.01	<.0001	Tukey-Kramer	<.0001
fuel2	A	D	1.1168	0.2707	124	4.13	<.0001	Tukey-Kramer	0.0013
fuel2	A	E	1.3211	0.2675	124	4.94	<.0001	Tukey-Kramer	<.0001
fuel2	A	F	0.7963	0.2667	124	2.99	0.0034	Tukey-Kramer	0.0515
fuel2	A	G	1.6016	0.2785	124	5.75	<.0001	Tukey-Kramer	<.0001
fuel2	B	C	0.3081	0.2547	124	1.21	0.2286	Tukey-Kramer	0.8891
fuel2	B	D	0.1001	0.2613	124	0.38	0.7022	Tukey-Kramer	0.9997
fuel2	B	E	0.3045	0.2580	124	1.18	0.2402	Tukey-Kramer	0.9004
fuel2	B	F	-0.2203	0.2577	124	-0.85	0.3943	Tukey-Kramer	0.9783
fuel2	B	G	0.5850	0.2690	124	2.17	0.0315	Tukey-Kramer	0.3168
fuel2	C	D	-0.2080	0.2640	124	-0.79	0.4324	Tukey-Kramer	0.9858
fuel2	C	E	-0.00363	0.2601	124	-0.01	0.9889	Tukey-Kramer	1.0000
fuel2	C	F	-0.5284	0.2608	124	-2.03	0.0449	Tukey-Kramer	0.4038
fuel2	C	G	0.2769	0.2718	124	1.02	0.3103	Tukey-Kramer	0.9488
fuel2	D	E	0.2044	0.2674	124	0.76	0.4463	Tukey-Kramer	0.9879
fuel2	D	F	-0.3204	0.2675	124	-1.20	0.2332	Tukey-Kramer	0.8937
fuel2	D	G	0.4848	0.2780	124	1.74	0.0837	Tukey-Kramer	0.5882
fuel2	E	F	-0.5248	0.2638	124	-1.99	0.0489	Tukey-Kramer	0.4269
fuel2	E	G	0.2805	0.2752	124	1.02	0.3101	Tukey-Kramer	0.9487
fuel2	F	G	0.8053	0.2752	124	2.93	0.0041	Tukey-Kramer	0.0605

Table B37: Least squares means for weighted fuel economy

Least Squares Means		
Effect	fuel2	Estimate

Least Squares Means		
Effect	fuel2	Estimate
fuel2	A	25.9131
fuel2	B	24.9616
fuel2	C	24.8159
fuel2	D	24.8355
fuel2	E	24.6606
fuel2	F	25.1813
fuel2	G	24.4256

Table B38: Multiple comparisons and p values for weighted fuel economy

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.9515	0.1661	124	5.73	<.0001	Tukey-Kramer	<.0001
fuel2	A	C	1.0972	0.1683	124	6.52	<.0001	Tukey-Kramer	<.0001
fuel2	A	D	1.0775	0.1723	124	6.25	<.0001	Tukey-Kramer	<.0001
fuel2	A	E	1.2525	0.1703	124	7.36	<.0001	Tukey-Kramer	<.0001
fuel2	A	F	0.7318	0.1698	124	4.31	<.0001	Tukey-Kramer	0.0006
fuel2	A	G	1.4875	0.1773	124	8.39	<.0001	Tukey-Kramer	<.0001
fuel2	B	C	0.1457	0.1621	124	0.90	0.3704	Tukey-Kramer	0.9721
fuel2	B	D	0.1261	0.1663	124	0.76	0.4499	Tukey-Kramer	0.9884
fuel2	B	E	0.3010	0.1643	124	1.83	0.0693	Tukey-Kramer	0.5290
fuel2	B	F	-0.2197	0.1640	124	-1.34	0.1829	Tukey-Kramer	0.8320
fuel2	B	G	0.5360	0.1712	124	3.13	0.0022	Tukey-Kramer	0.0345
fuel2	C	D	-0.01967	0.1681	124	-0.12	0.9070	Tukey-Kramer	1.0000
fuel2	C	E	0.1552	0.1656	124	0.94	0.3502	Tukey-Kramer	0.9656
fuel2	C	F	-0.3654	0.1660	124	-2.20	0.0296	Tukey-Kramer	0.3026
fuel2	C	G	0.3903	0.1730	124	2.26	0.0258	Tukey-Kramer	0.2740
fuel2	D	E	0.1749	0.1702	124	1.03	0.3062	Tukey-Kramer	0.9467
fuel2	D	F	-0.3457	0.1703	124	-2.03	0.0444	Tukey-Kramer	0.4008
fuel2	D	G	0.4100	0.1770	124	2.32	0.0222	Tukey-Kramer	0.2446
fuel2	E	F	-0.5207	0.1679	124	-3.10	0.0024	Tukey-Kramer	0.0376
fuel2	E	G	0.2351	0.1752	124	1.34	0.1821	Tukey-Kramer	0.8308
fuel2	F	G	0.7557	0.1752	124	4.31	<.0001	Tukey-Kramer	0.0006

Table B39: Least squares means for cumulative PM mass

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	121	1.60	0.1534
Least Squares Means				
Effect	**fuel2**	**Estimate**	**Back transformed**	
fuel2	A	-0.1377	0.87136006	
fuel2	B	-0.08711	0.91657627	
fuel2	C	-0.2047	0.81489175	
fuel2	D	-0.3127	0.73146932	
fuel2	E	-0.2533	0.77623498	
fuel2	F	-0.09146	0.91259782	
fuel2	G	0.1301	1.13894227	

Table B40: Least squares means for cold-start PN

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	111	0.90	0.4955
Least Squares Means				
Effect	**fuel2**	**Estimate**	**Back transformed**	
fuel2	A	24.2108	3.2705E+10	
fuel2	B	24.3699	3.8345E+10	
fuel2	C	24.5932	4.7939E+10	
fuel2	D	24.8017	5.9053E+10	
fuel2	E	24.1882	3.1974E+10	
fuel2	F	24.6866	5.2633E+10	

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
fuel2	G	24.6772		5.214E+10

Table B41: Least squares means for weighted PN

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
fuel2	6	110	1.25	0.2870
Least Squares Means				
Effect	fuel2	Estimate	Back transformed	
fuel2	A	23.4463	1.5226E+10	
fuel2	B	23.5476	1.685E+10	
fuel2	C	23.6962	1.9549E+10	
fuel2	D	23.9185	2.4416E+10	
fuel2	E	23.3128	1.3324E+10	
fuel2	F	23.8463	2.2715E+10	
fuel2	G	23.8649	2.3142E+10	

Table B42: Least squares means for formaldehyde

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	8.4646	4743.8295
fuel2	B	8.0793	3226.97356
fuel2	C	8.6621	5779.65921
fuel2	D	8.5143	4985.55495
fuel2	E	8.6375	5639.21415

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	F	8.3857	4383.92622
fuel2	G	8.3434	4202.35348

Table B43: Multiple comparisons and p values for formaldehyde

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.3853	0.1271	119	3.03	0.0030	Tukey-Kramer	0.0459
fuel2	A	C	-0.1975	0.1324	119	-1.49	0.1384	Tukey-Kramer	0.7492
fuel2	A	D	-0.04967	0.1317	119	-0.38	0.7066	Tukey-Kramer	0.9998
fuel2	A	E	-0.1729	0.1317	119	-1.31	0.1917	Tukey-Kramer	0.8446
fuel2	A	F	0.07896	0.1299	119	0.61	0.5445	Tukey-Kramer	0.9965
fuel2	A	G	0.1212	0.1376	119	0.88	0.3803	Tukey-Kramer	0.9748
fuel2	B	C	-0.5828	0.1264	119	-4.61	<.0001	Tukey-Kramer	0.0002
fuel2	B	D	-0.4350	0.1255	119	-3.47	0.0007	Tukey-Kramer	0.0126
fuel2	B	E	-0.5582	0.1255	119	-4.45	<.0001	Tukey-Kramer	0.0004
fuel2	B	F	-0.3064	0.1237	119	-2.48	0.0147	Tukey-Kramer	0.1775
fuel2	B	G	-0.2641	0.1314	119	-2.01	0.0467	Tukey-Kramer	0.4141
fuel2	C	D	0.1478	0.1305	119	1.13	0.2596	Tukey-Kramer	0.9167
fuel2	C	E	0.02455	0.1303	119	0.19	0.8509	Tukey-Kramer	1.0000
fuel2	C	F	0.2764	0.1294	119	2.14	0.0347	Tukey-Kramer	0.3388
fuel2	C	G	0.3187	0.1367	119	2.33	0.0214	Tukey-Kramer	0.2380
fuel2	D	E	-0.1232	0.1300	119	-0.95	0.3450	Tukey-Kramer	0.9637
fuel2	D	F	0.1286	0.1284	119	1.00	0.3186	Tukey-Kramer	0.9527
fuel2	D	G	0.1709	0.1360	119	1.26	0.2114	Tukey-Kramer	0.8700
fuel2	E	F	0.2519	0.1285	119	1.96	0.0522	Tukey-Kramer	0.4450
fuel2	E	G	0.2941	0.1362	119	2.16	0.0328	Tukey-Kramer	0.3256
fuel2	F	G	0.04225	0.1344	119	0.31	0.7538	Tukey-Kramer	0.9999

Table B44: Least squares means for acetaldehyde

Least Squares Means			
Effect	fuel2	Estimate	Back transformed

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	7.3413	1542.71634
fuel2	B	6.8486	942.560398
fuel2	C	7.4289	1683.9542
fuel2	D	7.2722	1439.71434
fuel2	E	7.3912	1621.65093
fuel2	F	7.3190	1508.69452
fuel2	G	7.2500	1408.10485

Table B45: Multiple comparisons and p values for acetaldehyde

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	A	B	0.4927	0.1438	119	3.43	0.0008	Tukey-Kramer	0.0143
fuel2	A	C	-0.08756	0.1497	119	-0.58	0.5597	Tukey-Kramer	0.9971
fuel2	A	D	0.06915	0.1489	119	0.46	0.6433	Tukey-Kramer	0.9992
fuel2	A	E	-0.04990	0.1489	119	-0.34	0.7382	Tukey-Kramer	0.9999
fuel2	A	F	0.02233	0.1470	119	0.15	0.8795	Tukey-Kramer	1.0000
fuel2	A	G	0.09137	0.1557	119	0.59	0.5584	Tukey-Kramer	0.9971
fuel2	B	C	-0.5803	0.1430	119	-4.06	<.0001	Tukey-Kramer	0.0017
fuel2	B	D	-0.4236	0.1419	119	-2.98	0.0034	Tukey-Kramer	0.0520
fuel2	B	E	-0.5426	0.1419	119	-3.82	0.0002	Tukey-Kramer	0.0039
fuel2	B	F	-0.4704	0.1399	119	-3.36	0.0010	Tukey-Kramer	0.0175
fuel2	B	G	-0.4014	0.1486	119	-2.70	0.0079	Tukey-Kramer	0.1072
fuel2	C	D	0.1567	0.1476	119	1.06	0.2904	Tukey-Kramer	0.9378
fuel2	C	E	0.03767	0.1473	119	0.26	0.7987	Tukey-Kramer	1.0000
fuel2	C	F	0.1099	0.1464	119	0.75	0.4543	Tukey-Kramer	0.9889
fuel2	C	G	0.1789	0.1546	119	1.16	0.2494	Tukey-Kramer	0.9084
fuel2	D	E	-0.1190	0.1470	119	-0.81	0.4197	Tukey-Kramer	0.9836
fuel2	D	F	-0.04682	0.1453	119	-0.32	0.7478	Tukey-Kramer	0.9999

Differences of Least Squares Means									
Effect	fuel2	fuel2	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P
fuel2	D	G	0.02222	0.1538	119	0.14	0.8854	Tukey-Kramer	1.0000
fuel2	E	F	0.07223	0.1453	119	0.50	0.6200	Tukey-Kramer	0.9989
fuel2	E	G	0.1413	0.1541	119	0.92	0.3610	Tukey-Kramer	0.9692
fuel2	F	G	0.06904	0.1520	119	0.45	0.6506	Tukey-Kramer	0.9993

Table B46: Least squares means for gas-phase naphthalene

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
fuel2	6	100	1.03	0.4080

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	6.8599	952.2717356
fuel2	B	6.2028	493.1306718
fuel2	C	7.2063	1346.895815
fuel2	D	6.7023	813.276509
fuel2	E	6.9322	1023.745943
fuel2	F	6.7925	890.1386259
fuel2	G	6.3229	556.1864926

Table B47: Least squares means for gas-phase 2-methylnaphthalene

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
fuel2	6	99	1.75	0.1164

Least Squares Means			
Effect	fuel2	Estimate	Back transformed
fuel2	A	5.7016	299.3459716

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**B**	5.5272	251.4388956
fuel2	**C**	5.9529	384.867839
fuel2	**D**	5.5579	259.2777809
fuel2	**E**	5.3993	221.2514859
fuel2	**F**	5.4299	228.1264316
fuel2	**G**	4.9351	139.0870505

Table B48: Least squares means for gas-phase 1-methylnaphthalene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	99	1.68	0.1344

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	5.1376	169.3065417
fuel2	**B**	4.9172	135.6195424
fuel2	**C**	5.4790	238.6069806
fuel2	**D**	5.0175	150.0332483
fuel2	**E**	4.9341	137.948033
fuel2	**F**	4.6860	107.4186368
fuel2	**G**	4.3478	76.30819767

Table B49: Least squares means for gas-phase fluorene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	2.00	0.0723

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Standard Error**
fuel2	**A**	4.2573	69.61905437
fuel2	**B**	3.6145	36.1327749

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Standard Error**
fuel2	**C**	4.8142	122.2481743
fuel2	**D**	4.0731	57.73877083
fuel2	**E**	4.4854	87.71242869
fuel2	**F**	4.2278	67.56622044
fuel2	**G**	4.2104	66.38348782

Table B50: Multiple comparisons and p values for gas-phase fluorene

Differences of Least Squares Means									
Effect	**fuel2**	**fuel2**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**	**Adjustment**	**Adj P**
fuel2	**A**	**B**	0.6428	0.3605	100	1.78	0.0776	Tukey-Kramer	0.5626
fuel2	**A**	**C**	-0.5570	0.3664	100	-1.52	0.1317	Tukey-Kramer	0.7322
fuel2	**A**	**D**	0.1841	0.3663	100	0.50	0.6164	Tukey-Kramer	0.9988
fuel2	**A**	**E**	-0.2281	0.3728	100	-0.61	0.5421	Tukey-Kramer	0.9963
fuel2	**A**	**F**	0.02947	0.3605	100	0.08	0.9350	Tukey-Kramer	1.0000
fuel2	**A**	**G**	0.04683	0.3663	100	0.13	0.8985	Tukey-Kramer	1.0000
fuel2	**B**	**C**	-1.1998	0.3664	100	-3.27	0.0015	Tukey-Kramer	0.0238
fuel2	**B**	**D**	-0.4587	0.3663	100	-1.25	0.2135	Tukey-Kramer	0.8717
fuel2	**B**	**E**	-0.8709	0.3728	100	-2.34	0.0215	Tukey-Kramer	0.2377
fuel2	**B**	**F**	-0.6133	0.3605	100	-1.70	0.0920	Tukey-Kramer	0.6169
fuel2	**B**	**G**	-0.5960	0.3663	100	-1.63	0.1069	Tukey-Kramer	0.6655
fuel2	**C**	**D**	0.7411	0.3723	100	1.99	0.0492	Tukey-Kramer	0.4269
fuel2	**C**	**E**	0.3289	0.3788	100	0.87	0.3873	Tukey-Kramer	0.9764
fuel2	**C**	**F**	0.5865	0.3664	100	1.60	0.1127	Tukey-Kramer	0.6823
fuel2	**C**	**G**	0.6038	0.3723	100	1.62	0.1079	Tukey-Kramer	0.6685
fuel2	**D**	**E**	-0.4122	0.3781	100	-1.09	0.2782	Tukey-Kramer	0.9296
fuel2	**D**	**F**	-0.1546	0.3663	100	-0.42	0.6738	Tukey-Kramer	0.9995
fuel2	**D**	**G**	-0.1373	0.3716	100	-0.37	0.7126	Tukey-Kramer	0.9998
fuel2	**E**	**F**	0.2576	0.3728	100	0.69	0.4913	Tukey-Kramer	0.9928
fuel2	**E**	**G**	0.2749	0.3781	100	0.73	0.4689	Tukey-Kramer	0.9906
fuel2	**F**	**G**	0.01735	0.3663	100	0.05	0.9623	Tukey-Kramer	1.0000

Table B51: Least squares means for gas-phase fluoranthene

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
fuel2	6	101	0.92	0.4834

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	2.3721	9.719880412
fuel2	**B**	2.1689	7.748655225
fuel2	**C**	2.7204	14.18639559
fuel2	**D**	2.1354	7.460430002
fuel2	**E**	2.5249	11.48964624
fuel2	**F**	2.5897	12.32577327
fuel2	**G**	2.6933	13.78037075

Table B52: Least squares means for gas-phase pyrene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	101	0.75	0.6100

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	2.6183	12.71239269
fuel2	**B**	2.3317	9.295428894
fuel2	**C**	2.7817	15.14644659
fuel2	**D**	2.3152	9.126948106
fuel2	**E**	2.4798	10.9388764
fuel2	**F**	2.9511	18.12698184
fuel2	**G**	2.6917	13.75674107

Table B53: Least squares means for gas-phase phenanthrene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	0.81	0.5619

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Standard Error**
fuel2	**A**	4.8690	130.1906611
fuel2	**B**	4.7352	113.8862337
fuel2	**C**	5.0784	160.5170231
fuel2	**D**	4.5919	98.68174747
fuel2	**E**	4.9238	137.5242135
fuel2	**F**	4.9823	145.8093578
fuel2	**G**	5.0373	154.0535085

Table B54: Least squares means for particle-phase phenanthrene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	99	1.34	0.2479

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	1.8830	5.573194897
fuel2	**B**	2.3158	9.133026098
fuel2	**C**	2.1479	7.566849111
fuel2	**D**	2.6542	13.21361062
fuel2	**E**	2.6340	12.92937612
fuel2	**F**	2.3215	9.190949271
fuel2	**G**	2.0221	6.55417205

Table B55: Least squares means for particle-phase 3-methylphenanthrene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	1.74	0.1199

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	0.9896	2.590158194

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**B**	1.1434	3.037417471
fuel2	**C**	1.3407	3.721717772
fuel2	**D**	1.3024	3.578113556
fuel2	**E**	0.8641	2.272869542
fuel2	**F**	0.3226	1.280712955
fuel2	**G**	0.3770	1.357904309

Table B56: Least squares means for particle-phase 2-methylphenanthrene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	1.10	0.3707

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	0.3987	1.389886586
fuel2	**B**	0.3197	1.276714688
fuel2	**C**	0.4563	1.478223741
fuel2	**D**	1.2434	3.367382547
fuel2	**E**	0.7705	2.060846407
fuel2	**F**	-0.07740	0.825519572
fuel2	**G**	0.5718	1.671452798

Table B57: Least squares means for particle-phase fluoranthene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	0.84	0.5449

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	0.4891	1.530847796
fuel2	**B**	0.6819	1.877631665

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**C**	0.6995	1.912746083
fuel2	**D**	0.8250	2.181880765
fuel2	**E**	0.3833	1.367118099
fuel2	**F**	0.4533	1.473496165
fuel2	**G**	-0.04210	0.858773898

Table B58: Least squares means for particle-phase pyrene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	1.72	0.1237

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	0.5544	1.640896134
fuel2	**B**	0.9281	2.429698182
fuel2	**C**	0.9067	2.376137781
fuel2	**D**	1.2364	3.343195622
fuel2	**E**	1.0384	2.724693887
fuel2	**F**	0.9135	2.393032896
fuel2	**G**	-0.1667	0.746453509

Table B59: Least squares means for gas-phase 1-nitronaphthalene

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	1.1303	3.086585336
fuel2	**B**	-0.9057	0.394258805
fuel2	**C**	-0.4680	0.616253524
fuel2	**D**	0.7700	2.149766254
fuel2	**E**	-0.3990	0.660990701
fuel2	**F**	-0.6104	0.533133572
fuel2	**G**	-1.0882	0.326822228

Table B60: Multiple comparisons and p values for gas-phase 1-nitronaphthalene

Differences of Least Squares Means									
Effect	**fuel2**	**fuel2**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**	**Adjustment**	**Adj P**
fuel2	**A**	**B**	2.0359	0.7001	90	2.91	0.0046	Tukey-Kramer	0.0663
fuel2	**A**	**C**	1.5983	0.6908	90	2.31	0.0230	Tukey-Kramer	0.2491
fuel2	**A**	**D**	0.3603	0.7018	90	0.51	0.6089	Tukey-Kramer	0.9986
fuel2	**A**	**E**	1.5293	0.7121	90	2.15	0.0344	Tukey-Kramer	0.3345
fuel2	**A**	**F**	1.7407	0.7389	90	2.36	0.0207	Tukey-Kramer	0.2298
fuel2	**A**	**G**	2.2185	0.7607	90	2.92	0.0045	Tukey-Kramer	0.0648
fuel2	**B**	**C**	-0.4377	0.6786	90	-0.64	0.5206	Tukey-Kramer	0.9950
fuel2	**B**	**D**	-1.6756	0.6895	90	-2.43	0.0171	Tukey-Kramer	0.1983
fuel2	**B**	**E**	-0.5066	0.6998	90	-0.72	0.4710	Tukey-Kramer	0.9908
fuel2	**B**	**F**	-0.2952	0.7287	90	-0.41	0.6863	Tukey-Kramer	0.9996
fuel2	**B**	**G**	0.1826	0.7504	90	0.24	0.8083	Tukey-Kramer	1.0000
fuel2	**C**	**D**	-1.2380	0.6782	90	-1.83	0.0713	Tukey-Kramer	0.5347
fuel2	**C**	**E**	-0.06896	0.6905	90	-0.10	0.9207	Tukey-Kramer	1.0000
fuel2	**C**	**F**	0.1424	0.7194	90	0.20	0.8435	Tukey-Kramer	1.0000
fuel2	**C**	**G**	0.6203	0.7388	90	0.84	0.4034	Tukey-Kramer	0.9800
fuel2	**D**	**E**	1.1690	0.7002	90	1.67	0.0985	Tukey-Kramer	0.6379
fuel2	**D**	**F**	1.3804	0.7305	90	1.89	0.0620	Tukey-Kramer	0.4924
fuel2	**D**	**G**	1.8582	0.7484	90	2.48	0.0149	Tukey-Kramer	0.1780
fuel2	**E**	**F**	0.2114	0.7407	90	0.29	0.7760	Tukey-Kramer	1.0000
fuel2	**E**	**G**	0.6892	0.7611	90	0.91	0.3676	Tukey-Kramer	0.9708
fuel2	**F**	**G**	0.4778	0.7873	90	0.61	0.5454	Tukey-Kramer	0.9964

Table B61: Least squares means for gas-phase 2-nitronaphthalene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	93	1.13	0.3522

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	-0.6674	0.503040751
fuel2	**B**	-0.08942	0.904461419

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**C**	0.2022	1.214092802
fuel2	**D**	-0.6478	0.513195542
fuel2	**E**	-0.5972	0.540350462
fuel2	**F**	-0.07154	0.920959038
fuel2	**G**	-0.2417	0.77529173

Table B62: Least squares means for gas-phase 2-methyl-4-nitronaphthalene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	1.01	0.4244

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	-1.8268	0.150927713
fuel2	**B**	-1.8930	0.140619273
fuel2	**C**	-1.0468	0.341059344
fuel2	**D**	-2.1480	0.106717359
fuel2	**E**	-1.9331	0.134698936
fuel2	**F**	-1.1700	0.300366941
fuel2	**G**	-1.4963	0.213957271

Table B63: Least squares means for particle-phase 1,3-dinitronaphthalene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	100	2.05	0.0662

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	-3.7599	0.022286069
fuel2	**B**	-2.5050	0.080675598
fuel2	**C**	-3.2339	0.038403525
fuel2	**D**	-2.3478	0.094579205
fuel2	**E**	-2.1225	0.118731924

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**F**	-3.5670	0.027240448
fuel2	**G**	-3.4738	0.02999901

Table B64: Least squares means for particle-phase 1-nitropyrene

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	98	1.06	0.3940

Least Squares Means			
Effect	**fuel2**	**Estimate**	**Back transformed**
fuel2	**A**	-2.0425	0.128704045
fuel2	**B**	-1.9542	0.140677774
fuel2	**C**	-2.6446	0.070033762
fuel2	**D**	-2.1115	0.120056246
fuel2	**E**	-1.9338	0.143597682
fuel2	**F**	-2.6201	0.071795583
fuel2	**G**	-1.7396	0.174590623

Table B65: Least squares means for OC

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
fuel2	6	122	1.59	0.1569
Least Squares Means				
Effect	**fuel2**	**Estimate**	**Back transformed**	
fuel2	A	-1.3648	0.25543176	
fuel2	B	-0.9836	0.37396241	
fuel2	C	-0.8934	0.40926189	
fuel2	D	-1.0143	0.3626562	
fuel2	E	-1.0963	0.33410499	

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
fuel2	F	-1.0538		0.34861051
fuel2	G	-1.0473		0.35088386

Appendix C

Table C1: Average weighted emissions (g/mile) and carbon balance fuel economy (miles/gallons) for the test vehicle/fuel combinations

	THCw Average						
	Federal ULSD	CARB Diesel	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Vehicle #1	0.032	0.022	0.032	0.026	0.029	0.027	0.024
Vehicle #2	0.061	0.055	0.064	0.062	0.055	0.059	0.061
Vehicle #3	0.018	0.016	0.021	0.017	0.022	0.019	0.018
Vehicle #4	0.051	0.041	0.049	0.041	0.045	0.044	0.037
Vehicle #5	0.083	0.055	0.067	0.079	0.060	0.062	0.068
Vehicle #6	0.018	0.014	0.014	0.013	0.024	0.013	0.012
Vehicle #7	0.040	0.032	0.044	0.032	0.034	0.032	0.031
Vehicle #8	0.059	0.063	0.055	0.051	0.053	0.067	0.066
	NMHCw Average						
Vehicle #1	0.015	0.009	0.018	0.012	0.015	0.013	0.011
Vehicle #2	0.038	0.033	0.041	0.032	0.034	0.030	0.035
Vehicle #3	0.008	0.005	0.008	0.007	0.009	0.005	0.005
Vehicle #4	0.021	0.017	0.020	0.015	0.019	0.014	0.013
Vehicle #5	0.068	0.035	0.049	0.059	0.046	0.044	0.051
Vehicle #6	0.007	0.004	0.007	0.004	0.014	0.005	0.005
Vehicle #7	0.025	0.019	0.029	0.019	0.021	0.018	0.016
Vehicle #8	0.010	0.011	0.013	0.009	0.014	0.011	0.015
	CH_4w Average						
Vehicle #1	0.020	0.015	0.016	0.016	0.018	0.016	0.015
Vehicle #2	0.026	0.026	0.027	0.035	0.025	0.034	0.029
Vehicle #3	0.012	0.013	0.016	0.012	0.015	0.016	0.016
Vehicle #4	0.034	0.028	0.034	0.029	0.030	0.035	0.028
Vehicle #5	0.018	0.023	0.020	0.024	0.017	0.022	0.020
Vehicle #6	0.013	0.011	0.008	0.010	0.011	0.010	0.008
Vehicle #7	0.017	0.015	0.017	0.015	0.015	0.016	0.017

Vehicle #8	0.057	0.059	0.048	0.048	0.046	0.065	0.059
	COw Average						
Vehicle #1	0.137	0.072	0.162	0.111	0.119	0.126	0.099
Vehicle #2	0.547	0.336	0.526	0.451	0.432	0.421	0.434
Vehicle #3	0.097	0.057	0.116	0.080	0.125	0.083	0.080
Vehicle #4	0.097	0.080	0.126	0.105	0.104	0.098	0.028
Vehicle #5	0.636	0.501	0.566	0.663	0.566	0.638	0.709
Vehicle #6	0.117	0.049	0.085	0.059	0.108	0.055	0.059
Vehicle #7	0.107	0.074	0.103	0.082	0.081	0.091	0.074
Vehicle #8	0.112	0.141	0.141	0.093	0.123	0.141	0.131
	NOxw Average						
Vehicle #1	0.041	0.045	0.028	0.028	0.033	0.046	0.031
Vehicle #2	0.144	0.150	0.173	0.149	0.181	0.138	0.142
Vehicle #3	0.034	0.047	0.035	0.040	0.039	0.030	0.043
Vehicle #4	0.035	0.043	0.049	0.039	0.041	0.048	0.045
Vehicle #5	0.159	0.143	0.139	0.165	0.198	0.144	0.165
Vehicle #6	0.231	0.240	0.279	0.235	0.260	0.259	0.243
Vehicle #7	0.030	0.037	0.036	0.036	0.037	0.044	0.035
Vehicle #8	0.053	0.063	0.052	0.062	0.053	0.066	0.054
	CO_2w Average						
Vehicle #1	417	408	429	419	418	409	412
Vehicle #2	731	734	740	709	734	726	731
Vehicle #3	260	262	275	271	271	268	267
Vehicle #4	421	429	424	417	432	421	427
Vehicle #5	789	817	807	791	825	767	792
Vehicle #6	654	656	659	661	657	645	651
Vehicle #7	296	293	295	296	296	293	293
Vehicle #8	396	394	397	398	413	394	404
	Carbon Balance FEw Average						
Vehicle #1	26.6	26.2	25.2	25.6	25.8	26.3	25.5
Vehicle #2	15.1	14.5	14.6	14.8	14.7	14.8	14.6
Vehicle #3	42.6	40.7	39.4	39.6	39.9	40.2	39.3
Vehicle #4	26.3	24.9	25.5	25.7	25.0	25.6	24.6
Vehicle #5	14.0	13.2	13.4	13.4	13.1	14.0	13.3
Vehicle #6	16.9	16.3	16.3	16.2	16.4	16.7	16.2
Vehicle #7	37.3	36.7	36.6	36.2	36.4	36.8	35.9
Vehicle #8	28.0	27.1	27.2	26.9	26.2	27.3	26.0

Table C2: Cycle-based PM mass emissions (mg/mile)

	Vehicle #1	Vehicle #2	Vehicle #3	Vehicle #4	Vehicle #5	Vehicle #6	Vehicle #7	Vehicle #8
Federal ULSD	0.75	1.52	0.18	0.99	2.18	2.65	0.73	0.68
CARB Diesel	1.26	2.12	0.26	1.02	1.93	1.36	0.60	0.60
Fed/SME-20	1.45	1.45	0.62	0.96	1.35	1.45	0.36	0.52
Fed/AFME-20	0.78	0.64	0.48	1.13	0.87	1.04	0.40	1.22
Fed/WCO-20	0.30	1.18	0.31	1.57	0.94	2.31	0.35	0.96
Fed/HVO-20	0.90	1.71	0.37	1.35	1.50	2.00	0.65	0.68
CARB/WCO-20	1.33	0.93	0.88	0.85	2.42	1.47	0.80	0.74

Table C3: Average weighted particle number emissions (particles/mile)

	Federal ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Vehicle #1	1.3699E+11	2.5606E+11	1.4055E+11	1.5478E+11	1.1357E+11	9.3367E+10	1.1938E+11
Vehicle #2	1.7060E+11	1.3703E+11	8.0970E+10	2.7200E+10	2.1994E+10	2.7623E+10	6.4027E+10
Vehicle #3	1.1868E+10	1.3765E+10	2.4971E+10	1.9704E+11	5.2160E+10	1.2932E+10	2.7491E+10
Vehicle #4	1.8989E+10	2.1574E+10	3.8112E+10	2.7090E+10	2.9433E+10	3.7038E+10	1.7124E+10
Vehicle #5	2.4069E+09	2.8700E+09	1.1178E+09	2.7282E+09	3.0456E+09	4.2168E+09	3.2468E+09
Vehicle #6	3.0608E+10	1.6467E+10	2.7156E+10	2.8242E+10	4.0827E+09	6.1371E+10	2.7636E+10
Vehicle #7	6.0422E+09	7.4305E+08	1.7559E+09	1.0301E+10	2.4375E+09	2.7754E+09	1.5522E+10
Vehicle #8	1.0599E+10	3.2045E+10	5.0502E+10	7.8220E+09	1.6707E+10	5.4498E+10	2.7432E+10

Table C4: Average weighted formaldehyde and acetaldehyde emissions (µg/mile)

	Formaldehyde						
	Federal ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Vehicle #1	3543.11	2640.01	8862.72	7045.30	2363.63	10156.08	4054.39
Vehicle #2	23470.97	13640.84	21170.88	18063.27	17604.70	14219.30	11198.73
Vehicle #3	2160.38	1343.24	0.00	1468.99	3996.21	2037.56	2008.66
Vehicle #4	7415.22	2637.97	3581.87	6565.03	5571.03	7699.53	8901.01
Vehicle #5	13364.28	10907.81	11163.07	6406.56	13961.16	11608.09	9346.51
Vehicle #6	2350.20	2150.73	2893.87	2807.90	5465.21	2741.87	1835.22
Vehicle #7	3968.16	2962.77	4786.39	3632.91	4300.29	1731.71	3253.83
Vehicle #8	1371.32	1438.90	2779.58	1598.66	3281.07	1251.14	2841.68
	Acetaldehyde						
Vehicle #1	797.10	632.37	2047.58	1565.77	353.18	2925.94	885.13
Vehicle #2	8585.19	4503.52	7414.71	5258.81	5640.61	5258.81	3431.55
Vehicle #3	780.78	445.87	0.00	447.34	1317.33	673.09	609.87
Vehicle #4	2256.81	811.39	1889.00	2391.74	2515.08	2702.30	962.67
Vehicle #5	5731.96	2002.23	3234.01	4860.36	3349.48	4102.87	12000.85
Vehicle #6	1405.08	1149.30	1535.58	728.95	1957.58	653.29	877.32
Vehicle #7	1015.40	623.52	1056.51	815.26	1600.72	1060.88	971.40
Vehicle #8	367.85	378.34	542.94	598.47	655.71	381.20	762.92

Table C5: Average nitrogenous emissions for Vehicle #4 to Vehicle #8 (g/mile)

	NO Average						
	Federal ULSD	CARB Diesel	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Vehicle #4	0.0033	0.0039	0.0145	0.0049	0.0090	0.0005	0.0048
Vehicle #5	0.1078	0.0997	0.0731	0.0639	0.1354	0.0920	0.1070
Vehicle #6	0.1161	0.1111	0.1631	0.1185	0.1491	0.1381	0.1643
Vehicle #7	0.0055	0.0119	0.0292	0.0109	0.0124	0.0192	0.0090
Vehicle #8	0.0008	0.0042	0.0030	0.0000	0.0038	0.0042	0.0043
	NO2 Average						
Vehicle #4	0.028	0.032	0.026	0.031	0.033	0.028	0.037
Vehicle #5	0.027	0.036	0.054	0.034	0.044	0.044	0.045
Vehicle #6	0.081	0.104	0.076	0.081	0.057	0.093	0.052
Vehicle #7	0.026	0.020	0.014	0.025	0.021	0.028	0.021
Vehicle #8	0.059	0.062	0.053	0.066	0.043	0.063	0.054
	N2O Average						
Vehicle #4	0.009	0.013	0.013	0.010	0.008	0.012	0.009
Vehicle #5	0.066	0.064	0.054	0.034	0.068	0.062	0.061
Vehicle #6	0.017	0.011	0.014	0.014	0.014	0.014	0.010
Vehicle #7	0.019	0.019	0.020	0.022	0.021	0.025	0.017
Vehicle #8	0.016	0.014	0.017	0.015	0.014	0.013	0.012
	NO:NO2 Ratio						
Vehicle #4	0.106	0.103	2.040	0.149	0.270	0.017	0.116
Vehicle #5	7.074	2.802	2.048	1.734	3.096	2.168	2.399
Vehicle #6	1.451	1.084	2.155	1.465	2.637	1.502	3.318
Vehicle #7	0.220	0.595	2.306	0.429	0.586	0.700	0.425
Vehicle #8	0.013	0.067	0.064	0.000	0.092	0.067	0.082

Table C6: Average OC emissions (mg/mile)

	Federal ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Vehicle #1	0.064	0.080	0.302	0.031	0.040	0.163	0.057
Vehicle #2	0.253	0.152	0.160	0.157	0.162	0.141	0.171
Vehicle #3	0.010	0.000	0.000	0.000	0.011	0.030	0.000
Vehicle #4	0.727	0.126	0.186	0.327	0.302	0.552	0.401
Vehicle #5	0.285	0.710	0.346	0.068	0.250	0.317	0.587
Vehicle #6	0.447	0.320	0.770	0.384	0.576	0.292	0.705
Vehicle #7	0.116	0.031	0.074	0.193	0.186	0.309	0.121
Vehicle #8	0.148	0.125	0.171	0.139	0.233	0.250	0.290

Table C7: Average NH_3 emissions (mg/mile)

	Federal ULSD	CARB Diesel	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Vehicle #1	17.5	7.5	5.5	14.6	11.3	17.4	10.0
Vehicle #2	7.4	7.5	7.6	5.1	6.3	7.2	7.8
Vehicle #3	1.2	2.5	1.6	1.4	1.8	1.3	0.9
Vehicle #4	NA	0.2	0.4	NA	0.1	NA	NA
Vehicle #5	NA	1.0	0.0	3.2	0.7	NA	NA
Vehicle #6	0.8	0.7	0.3	1.3	0.4	-0.1	NA
Vehicle #7	1.4	0.3	9.9	0.9	0.4	0.6	2.0
Vehicle #8	0.7	0.5	5.1	0.2	1.3	0.5	0.7

Table C8: Average emissions during regeneration emissions testing for Vehicle #1 and Vehicle #3

	Vehicle #1		
	Baseline HWFET	**Federal ULSD**	**Fed/SME-20**
THC, g/mi	0.0047	0.039	0.065
NMHC, g/mi	0.0018	0.003	0.004
CH4, g/mi	0.0033	0.042	0.070
CO, g/mi	0.0000	0.008	0.013
NOx, g/mi	0.0761	0.103	0.096
CO2, g/mi	263	389	365
FE, mi/gallon	38.7	26.2	28.4
PM mass, mg/mi	NA	11.54	11.10
PN, #/mi	5.21E+03	3.56E+14	1.74E+15
BC, µg/mi	34.11 (x10)	248.62	353.94
EC, mg/mi	NA	0.560	0.516
OC, mg/mi	NA	0.266	0.252
Formal, µg/mi	0.539	0.674	1.293
Acetal x 5, µg/mi	0.000	0.043	0.203
Propional x 10, µg/mi	0.000	0.100	0.033
Butyral x 10, µg/mi	0.000	0.000	0.040
Benzal x 10, µg/mi	0.000	0.172	0.000
Hexanal x 10, µg/mi	0.000	0.088	0.000
	Vehicle #3		
THC, g/mi	0.007	0.010	0.027
NMHC, g/mi	0.003	0.002	0.018
CH4, g/mi	0.005	0.009	0.010
CO, g/mi	0.015	0.009	0.053
NOx, g/mi	0.085	0.230	0.362
CO2, g/mi	165	196	224
FE, mi/gallon	61.7	52.7	45.5
PM mass, mg/mi	0.66	21.04	12.52
PN, #/mi	8.20E+13	9.03E+14	6.48E+14
Soot Mass, mg/mi	0.52 (x10)	1.417	1.306
EC, mg/mi	0.040	1.114	1.331
OC, mg/mi	0.252	0.517	0.655
Formal, µg/mi	0.238	0.287	1.405
Acetal, µg/mi	0.000	0.023	0.196
Propional, µg/mi	0.000	0.013	0.015
Crotonal, µg/mi	0.060	0.067	0.036
Butyral, µg/mi	0.000	0.034	0.123
Benzal, µg/mi	0.000	0.008	0.012

Appendix D

Table D1: Gas-phase PAH emissions for Vehicle #1

Component (ng/mile)	Fed ULSD	CARB USLD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Naphthalene	253.91 ± 195.88	473.53 ± 221.80	2272.57 ± 822.60	815.15 ± 357.26	2014.97 ± 68.10	441.20 ± 559.90	50.22 ± 71.01
Quinoline	0.00 ± 0.00	0.00 ± 0.00	2.08 ± 2.95	2.06 ± 2.92	42.81 ± 46.02	5.13 ± 7.26	0.00 ± 0.00
2-methylnaphthalene	197.27 ± 95.12	436.48 ± 134.89	804.52 ± 425.48	420.13 ± 103.08	764.95 ± 69.05	230.86 ± 64.31	46.69 ± 60.50
1-methylnaphthalene	90.33 ± 41.32	240.58 ± 26.31	509.03 ± 325.65	234.23 ± 78.60	423.32 ± 9.65	151.98 ± 0.28	25.51 ± 34.50
Biphenyl	32.68 ± 16.56	78.88 ± 25.27	122.11 ± 58.81	76.74 ± 4.41	77.64 ± 28.64	26.74 ± 9.15	41.09 ± 58.10
2-methylbiphenyl	2230.79 ± 477.44	2694.35 ± 137.01	2054.23 ± 588.42	1495.97 ± 283.48	3392.02 ± 551.37	3709.07 ± 903.28	2949.50 ± 2776.74
2,6+2,7-dimethylnaphthalene	19.83 ± 28.04	173.64 ± 83.67	318.07 ± 153.76	154.58 ± 53.79	87.85 ± 24.28	0.00 ± 0.00	12.71 ± 3.34
1,3+1,6+1,7dimethylnaphth	48.70 ± 29.05	316.29 ± 26.86	624.39 ± 343.51	293.26 ± 74.25	171.51 ± 48.61	47.96 ± 36.22	92.63 ± 56.12
1,4+1,5+2,3-dimethylnaphth	33.81 ± 29.18	79.93 ± 11.87	131.69 ± 51.16	86.73 ± 28.96	90.79 ± 32.70	15.79 ± 12.08	29.33 ± 31.15
Acenaphthylene	5.99 ± 8.47	8.80 ± 12.44	20.23 ± 5.06	11.78 ± 16.66	26.70 ± 37.76	5.92 ± 0.17	0.00 ± 0.00
1,2-dimethylnaphthalene	0.00 ± 0.00	19.64 ± 27.78	30.21 ± 13.67	15.93 ± 8.30	10.12 ± 8.34	4.92 ± 6.96	0.00 ± 0.00
1,8-dimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthene	5.03 ± 7.11	10.75 ± 15.20	56.80 ± 43.42	39.56 ± 8.47	66.87 ± 28.78	0.00 ± 0.00	0.00 ± 0.00
3-methylbiphenyl	850.00 ± 337.86	851.05 ± 537.93	1159.69 ± 77.26	0.00 ± 0.00	0.00 ± 0.00	1038.10 ± 784.90	1234.89 ± 851.19
4-methylbiphenyl	461.53 ± 16.64	779.86 ± 182.50	410.05 ± 85.14	0.00 ± 0.00	93.64 ± 132.43	467.87 ± 354.23	471.94 ± 374.76
1+2ethylnaphthalene	140.72 ± 91.40	182.03 ± 27.72	313.10 ± 68.19	192.96 ± 41.16	192.65 ± 18.70	155.30 ± 25.46	124.33 ± 28.18
1-ethyl-2-methylnaphthalene	2.07 ± 2.93	4.98 ± 7.05	53.43 ± 22.94	33.63 ± 8.25	5.04 ± 7.13	2.11 ± 2.99	15.25 ± 15.54
2,3,5+I-trimethylnaphthalene	13.91 ± 19.67	21.55 ± 16.37	156.78 ± 19.89	95.62 ± 3.88	25.81 ± 36.50	0.00 ± 0.00	15.91 ± 22.50

B-trimethylnaphthalene	23.67 ± 33.48	70.16 ± 33.47	182.71 ± 69.92	126.93 ± 12.91	23.95 ± 0.31	14.73 ± 3.75	25.12 ± 35.53
A-trimethylnaphthalene	28.11 ± 39.75	102.31 ± 50.19	239.94 ± 60.54	180.08 ± 25.59	50.57 ± 50.15	5.98 ± 4.36	73.97 ± 104.61
C-trimethylnaphthalene	38.58 ± 29.14	58.37 ± 0.38	192.24 ± 106.95	100.27 ± 49.78	26.70 ± 37.76	14.48 ± 20.48	64.20 ± 90.80
2-ethyl-1-methylnaphthalene	0.00 ± 0.00	2.05 ± 2.90	4.03 ± 0.20	10.02 ± 8.32	16.06 ± 16.73	0.00 ± 0.00	2.13 ± 3.01
E-trimethylnaphthalene	4.44 ± 6.28	26.22 ± 16.34	100.67 ± 4.94	76.73 ± 3.94	7.42 ± 10.49	0.00 ± 0.00	8.75 ± 0.53
2,4,5-trimethylnaphthalene	0.00 ± 0.00	2.03 ± 2.88	0.00 ± 0.00	7.99 ± 11.29	0.00 ± 0.00	0.00 ± 0.00	5.17 ± 7.32
F-trimethylnaphthalene	12.43 ± 17.58	18.63 ± 16.39	84.27 ± 8.05	27.74 ± 4.09	10.10 ± 12.57	0.00 ± 0.00	14.52 ± 20.53
Fluorene	134.86 ± 70.40	0.00 ± 0.00	366.41 ± 367.40	198.90 ± 20.27	171.91 ± 14.90	86.41 ± 35.10	55.95 ± 77.54
1,4,5-trimethylnaphthalene	11.84 ± 16.74	0.00 ± 0.00	2.78 ± 3.93	2.96 ± 4.18	0.00 ± 0.00	0.00 ± 0.00	5.83 ± 0.36
J-trimethylnaphthalene	11.84 ± 16.74	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A-Methylfluorene	4.17 ± 0.04	2.03 ± 2.88	15.33 ± 7.37	21.85 ± 8.41	7.16 ± 4.14	0.00 ± 0.00	15.91 ± 22.50
B-Methylfluorene	2.98 ± 0.03	1.47 ± 2.07	5.65 ± 3.79	0.00 ± 0.00	2.99 ± 0.04	2.96 ± 0.09	4.19 ± 5.92
1-Methylfluorene	3.59 ± 5.08	0.59 ± 0.83	0.00 ± 0.00	10.04 ± 4.20	0.59 ± 0.84	0.58 ± 0.82	3.35 ± 4.74
9-fluorenone	19.15 ± 21.22	4.98 ± 7.05	13.99 ± 19.78	74.99 ± 16.92	49.12 ± 4.86	23.25 ± 32.88	23.43 ± 33.14
Dibenzothiophene	3.59 ± 5.08	0.00 ± 0.00	1.15 ± 0.06	1.18 ± 0.00	0.59 ± 0.84	1.18 ± 0.03	0.61 ± 0.86
Phenanthrene	92.33 ± 9.22	131.18 ± 48.69	152.45 ± 7.49	200.66 ± 28.61	152.08 ± 91.19	77.09 ± 14.81	115.04 ± 48.20
Anthracene	6.51 ± 9.21	3.52 ± 4.98	21.39 ± 5.11	10.05 ± 12.55	3.56 ± 5.03	1.18 ± 0.03	4.21 ± 4.38
Xanthone	2.98 ± 0.03	11.66 ± 4.05	2.88 ± 0.14	20.64 ± 16.63	59.79 ± 11.94	5.98 ± 4.36	2.92 ± 0.18
1,4-Naphthoquinone	11.91 ± 0.10	5.84 ± 0.04	11.51 ± 0.56	5.89 ± 8.33	5.93 ± 8.39	0.00 ± 0.00	2.79 ± 3.95
Acenaphthenequinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylphenanthrene	8.97 ± 8.50	20.40 ± 8.12	11.41 ± 3.50	17.73 ± 12.58	5.96 ± 4.16	1.45 ± 2.05	22.96 ± 10.95
2-methylphenanthrene	19.05 ± 0.17	24.52 ± 0.16	4.13 ± 4.27	21.87 ± 20.94	0.60 ± 0.85	4.20 ± 4.30	50.38 ± 9.28

Perinaphthenone	22.07 ± 8.61	16.71 ± 23.63	42.12 ± 30.51	5.03 ± 7.11	43.14 ± 4.78	44.38 ± 62.77	7.13 ± 4.55
2-methylanthracene	2.98 ± 0.03	2.92 ± 0.02	4.16 ± 5.89	1.48 ± 2.09	2.99 ± 0.04	5.85 ± 4.01	0.00 ± 0.00
4,5-methylenephenanthrene	5.95 ± 0.05	2.93 ± 4.15	2.98 ± 4.21	8.85 ± 4.15	3.02 ± 4.27	3.02 ± 4.27	2.79 ± 3.95
9-methylphenanthrene	4.15 ± 4.17	15.75 ± 4.03	0.00 ± 0.00	12.99 ± 0.04	12.46 ± 17.62	4.20 ± 4.30	9.79 ± 3.52
1-methylphenanthrene	0.00 ± 0.00	2.03 ± 2.88	1.94 ± 2.75	10.04 ± 0.03	0.00 ± 0.00	2.11 ± 2.99	7.54 ± 10.66
Anthrone	14.87 ± 4.08	32.07 ± 12.18	11.11 ± 15.71	5.92 ± 8.37	14.83 ± 20.98	12.08 ± 17.08	23.59 ± 9.68
9-methylanthracene	4.17 ± 0.04	2.05 ± 2.90	1.94 ± 2.75	4.13 ± 0.01	0.00 ± 0.00	2.11 ± 2.99	4.08 ± 0.25
Anthraquinone	2.96 ± 4.18	0.00 ± 0.00	11.51 ± 0.56	2.96 ± 4.18	11.92 ± 8.31	3.02 ± 4.27	0.00 ± 0.00
A-dimethylphenanthrene	7.99 ± 11.30	4.09 ± 0.03	39.54 ± 42.57	2.07 ± 2.93	2.08 ± 2.94	9.93 ± 8.07	47.22 ± 17.71
B-dimethylphenanthrene	0.59 ± 0.84	12.79 ± 16.43	6.55 ± 9.26	0.59 ± 0.84	0.00 ± 0.00	6.64 ± 9.39	0.61 ± 0.86
1,7-dimethylphenanthrene	7.16 ± 4.27	2.05 ± 2.90	7.00 ± 4.41	2.06 ± 2.92	2.08 ± 2.94	0.00 ± 0.00	4.75 ± 6.71
3,6-dimethylphenanthrene	0.00 ± 0.00	5.86 ± 8.29	2.78 ± 3.93	2.96 ± 4.18	5.99 ± 0.08	5.92 ± 0.17	2.79 ± 3.95
D-dimethylphenanthrene	1.50 ± 2.12	1.47 ± 2.07	0.00 ± 0.00	1.48 ± 2.09	2.99 ± 0.04	2.96 ± 0.09	2.92 ± 0.18
E-dimethylphenanthrene	2.96 ± 4.18	2.93 ± 4.15	2.78 ± 3.93	0.00 ± 0.00	14.89 ± 12.51	3.02 ± 4.27	0.00 ± 0.00
C-dimethylphenanthrene	4.15 ± 4.17	4.07 ± 4.10	4.13 ± 4.27	7.08 ± 0.02	55.24 ± 26.11	4.20 ± 4.30	3.96 ± 3.88
Fluoranthene	1.48 ± 2.09	0.00 ± 0.00	11.41 ± 3.50	11.80 ± 4.14	10.38 ± 14.68	0.00 ± 0.00	7.61 ± 10.76
Pyrene	47.53 ± 24.85	11.65 ± 8.18	97.18 ± 137.43	64.89 ± 24.85	14.89 ± 12.51	32.35 ± 11.59	21.30 ± 30.13
9-Anthraaldehyde	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Retene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(a)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.90 ± 4.10	3.04 ± 4.30
benzo(b)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
5-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

B-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	1.94 ± 2.75	2.07 ± 2.93	0.00 ± 0.00	4.92 ± 6.96	0.00 ± 0.00
1-MeFl+C-MeFl/Py	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1+3-methylfluoranthene	2.10 ± 2.97	0.00 ± 0.00	0.00 ± 0.00	2.07 ± 2.93	0.00 ± 0.00	2.03 ± 2.87	2.13 ± 3.01
4-methylpyrene	2.07 ± 2.93	2.05 ± 2.90	0.00 ± 0.00	4.13 ± 0.01	2.08 ± 2.94	0.00 ± 0.00	1.95 ± 2.76
C-MePy/MeFl	0.00 ± 0.00	2.05 ± 2.90	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	4.14 ± 0.12	0.00 ± 0.00
D-MePy/MeFl	2.07 ± 2.93	0.00 ± 0.00	1.94 ± 2.75	0.00 ± 0.00	2.11 ± 2.99	2.03 ± 2.87	0.00 ± 0.00
1-methylpyrene	5.97 ± 4.26	0.00 ± 0.00	1.49 ± 2.10	0.00 ± 0.00	0.00 ± 0.00	1.51 ± 2.13	0.00 ± 0.00
Benzonaphthothiophene	0.60 ± 0.85	0.00 ± 0.00	1.15 ± 0.06	0.00 ± 0.00	1.20 ± 0.02	0.00 ± 0.00	0.00 ± 0.00
benzo(c)phenanthrene	2.98 ± 0.03	0.00 ± 0.00	2.88 ± 0.14	2.95 ± 0.01	4.53 ± 6.41	1.45 ± 2.05	0.00 ± 0.00
Benzo(ghi)fluoranthene	2.98 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	1.47 ± 2.08	2.99 ± 0.04	1.51 ± 2.13	2.92 ± 0.18
9-phenylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	9.01 ± 4.35	5.92 ± 0.17	0.00 ± 0.00
6-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.03 ± 2.87	0.00 ± 0.00
Benz(a)anthracene	2.07 ± 2.93	0.00 ± 0.00	0.00 ± 0.00	2.07 ± 2.93	0.00 ± 0.00	4.14 ± 0.12	0.00 ± 0.00
Chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzanthrone	2.96 ± 4.18	0.00 ± 0.00	0.00 ± 0.00	2.96 ± 4.18	5.99 ± 0.08	0.00 ± 0.00	0.00 ± 0.00
Benz(a)anthracene-7,12-dione	5.99 ± 8.47	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7,12-dimethylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	29.45 ± 41.65	71.90 ± 9.39	33.21 ± 46.97	0.00 ± 0.00
Benzo(b)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(j)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Benzo(k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(a)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BeP	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.11 ± 2.99	0.00 ± 0.00	2.13 ± 3.01
BaP	0.00 ± 0.00	1.47 ± 2.07	1.49 ± 2.10	0.00 ± 0.00	1.48 ± 2.10	4.34 ± 6.14	0.00 ± 0.00
Perylene	0.00 ± 0.00	0.00 ± 0.00	1.49 ± 2.10	0.00 ± 0.00	14.86 ± 16.74	1.51 ± 2.13	1.52 ± 2.15
3-methylcholanthrene	1.19 ± 0.01	1.17 ± 0.01	1.15 ± 0.06	4.14 ± 4.19	4.22 ± 4.29	1.18 ± 0.03	0.56 ± 0.79
7-methylbenzo(a)pyrene	0.60 ± 0.85	0.00 ± 0.00	0.00 ± 0.00	24.25 ± 34.30	0.00 ± 0.00	0.60 ± 0.85	0.00 ± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.03 ± 2.87	0.00 ± 0.00
Indeno[123-cd]fluoranthene	3.00 ± 4.24	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah+ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.97 ± 4.20	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00 ± 0.00	7.92 ± 11.20	0.00 ± 0.00	0.00 ± 0.00	8.01 ± 11.33	0.00 ± 0.00	0.00 ± 0.00
Picene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.07 ± 2.93	5.14 ± 7.26	0.00 ± 0.00	0.00 ± 0.00
Benzo(ghi)perylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	4.13 ± 0.01	2.11 ± 2.99	2.11 ± 2.99	0.00 ± 0.00
Anthanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Triphenylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,l)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Dibenzo(a,e)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table D2: Gas-phase PAH emissions for the Vehicle #2

Component (ng/mile)	Fed ULSD	CARB USLD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Naphthalene	2916.37 ± 1603.86	1484.05 ± 1873.24	1652.05 ± 157.42	400.22 ± 409.71	1385.78 ± 1021.02	895.99 ± 1261.71	1029.47 ± 310.54
Quinoline	20.09 ± 0.37	2.65 ± 3.75	5.22 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	32.04 ± 37.73	17.16 ± 16.45
2-methylnaphthalene	641.91 ± 335.48	1215.31 ± 861.75	672.78 ± 26.70	262.56 ± 207.48	178.33 ± 59.28	817.60 ± 1051.22	290.61 ± 202.03
1-methylnaphthalene	327.04 ± 193.93	691.85 ± 556.77	400.52 ± 57.82	156.77 ± 136.14	132.23 ± 32.23	534.54 ± 755.95	224.26 ± 147.30
Biphenyl	77.74 ± 40.67	180.83 ± 114.13	130.53 ± 10.61	13.34 ± 18.86	13.49 ± 19.07	135.35 ± 191.42	121.73 ± 34.57
2-methylbiphenyl	374.57 ± 529.72	1068.87 ± 1511.61	0.00 ± 0.00	162.34 ± 229.58	402.89 ± 569.77	0.00 ± 0.00	1740.94 ± 29.78
2,6+2,7-dimethylnaphthalene	128.02 ± 7.59	420.71 ± 398.83	292.37 ± 57.87	27.99 ± 21.85	29.55 ± 41.78	223.81 ± 316.51	29.96 ± 42.37
1,3+1,6+1,7dimethylnaphth	235.76 ± 6.23	734.65 ± 758.90	553.38 ± 226.51	68.94 ± 3.73	59.17 ± 32.45	425.88 ± 602.28	6.72 ± 9.50
1,4+1,5+2,3-dimethylnaphth	12.70 ± 5.49	235.60 ± 215.71	165.57 ± 63.21	35.19 ± 4.50	16.90 ± 10.83	115.14 ± 162.84	36.71 ± 27.33
Acenaphthylene	11.02 ± 15.58	87.01 ± 102.08	7.46 ± 10.55	7.62 ± 10.78	7.69 ± 0.02	68.63 ± 97.06	11.73 ± 5.42
1,2-dimethylnaphthalene	2.64 ± 3.73	61.86 ± 48.67	2.61 ± 3.69	0.00 ± 0.00	2.70 ± 3.81	36.98 ± 52.30	6.61 ± 9.35
1,8-dimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	11.85 ± 16.76
Acenaphthene	56.91 ± 41.05	65.16 ± 9.60	117.10 ± 10.49	0.00 ± 0.00	21.87 ± 30.93	29.36 ± 41.52	25.00 ± 16.37
3-methylbiphenyl	436.99 ± 618.00	788.39 ± 1114.95	700.87 ± 991.18	248.29 ± 254.12	453.49 ± 161.78	0.00 ± 0.00	0.00 ± 0.00
4-methylbiphenyl	96.15 ± 61.37	253.95 ± 359.14	78.32 ± 36.96	315.01 ± 7.20	200.10 ± 98.48	149.20 ± 135.52	0.00 ± 0.00

1+2ethylnaphthalene	149.77 ± 55.14	299.50 ± 237.90	228.97 ± 52.63	62.29 ± 70.35	63.13 ± 49.13	181.87 ± 257.20	107.37 ± 9.94
1-ethyl-2-methylnaphthalene	19.90 ± 20.68	63.30 ± 89.52	132.00 ± 73.77	0.00 ± 0.00	0.00 ± 0.00	21.73 ± 30.73	0.00 ± 0.00
2,3,5+I-trimethylnaphthalene	23.95 ± 16.22	150.48 ± 212.80	385.57 ± 158.03	13.65 ± 19.31	25.71 ± 36.36	29.36 ± 41.52	0.00 ± 0.00
B-trimethylnaphthalene	33.91 ± 47.96	298.62 ± 317.42	413.90 ± 216.03	0.00 ± 0.00	0.00 ± 0.00	45.75 ± 64.70	0.00 ± 0.00
A-trimethylnaphthalene	111.36 ± 24.27	366.39 ± 355.58	477.29 ± 279.29	16.60 ± 23.48	44.13 ± 62.40	74.35 ± 105.14	1.98 ± 2.79
C-trimethylnaphthalene	63.67 ± 48.50	250.00 ± 332.57	350.54 ± 84.21	56.80 ± 49.02	3.84 ± 5.43	0.00 ± 0.00	0.00 ± 0.00
2-ethyl-1-methylnaphthalene	2.64 ± 3.73	10.01 ± 14.16	20.14 ± 0.01	0.00 ± 0.00	5.38 ± 0.02	0.00 ± 0.00	2.77 ± 3.91
E-trimethylnaphthalene	33.48 ± 0.61	117.46 ± 160.87	197.63 ± 94.84	0.00 ± 0.00	0.00 ± 0.00	24.78 ± 35.05	0.00 ± 0.00
2,4,5-trimethylnaphthalene	5.21 ± 0.09	24.20 ± 26.88	6.34 ± 8.96	0.00 ± 0.00	13.07 ± 0.04	2.67 ± 3.77	0.00 ± 0.00
F-trimethylnaphthalene	64.78 ± 6.44	115.05 ± 139.62	199.13 ± 57.92	0.00 ± 0.00	4.60 ± 6.51	4.58 ± 6.47	0.00 ± 0.00
Fluorene	474.79 ± 306.97	231.32 ± 146.72	1127.73 ± 73.29	114.49 ± 45.03	193.86 ± 44.08	135.10 ± 102.26	263.94 ± 58.16
1,4,5-trimethylnaphthalene	14.78 ± 10.25	15.16 ± 21.44	29.84 ± 31.66	0.00 ± 0.00	0.00 ± 0.00	3.81 ± 5.39	0.00 ± 0.00
J-trimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	14.92 ± 21.10	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A-Methylfluorene	16.42 ± 5.56	39.03 ± 5.90	113.39 ± 68.62	23.82 ± 15.36	2.70 ± 3.81	6.48 ± 9.17	13.27 ± 10.95
B-Methylfluorene	1.88 ± 2.66	14.96 ± 5.07	22.38 ± 5.28	1.91 ± 2.69	3.85 ± 0.01	1.91 ± 2.70	19.72 ± 22.39
1-Methylfluorene	24.10 ± 32.00	20.45 ± 26.82	124.56 ± 15.88	9.00 ± 0.21	0.77 ± 1.09	0.77 ± 1.08	0.78 ± 1.10
9-fluorenone	0.00 ± 0.00	13.72 ± 19.40	28.73 ± 40.62	8.94 ± 5.10	40.01 ± 16.43	2.68 ± 3.79	44.94 ± 44.84
Dibenzothiophene	1.49 ± 0.03	0.74 ± 1.05	4.47 ± 6.33	0.00 ± 0.00	0.00 ± 0.00	0.77 ± 1.08	0.79 ± 1.12
Phenanthrene	220.44 ± 109.22	262.66 ± 30.57	533.28 ± 52.48	71.62 ± 33.45	130.84 ± 71.08	137.53 ± 5.00	184.46 ± 35.25
Anthracene	16.46 ± 10.82	16.42 ± 10.35	27.59 ± 26.36	0.00 ± 0.00	0.77 ± 1.09	5.34 ± 5.39	0.00 ± 0.00
Xanthone	1.84 ± 2.60	33.74 ± 0.52	26.10 ± 31.63	1.84 ± 2.61	3.85 ± 0.01	3.82 ± 0.01	11.82 ± 11.22
1,4-Naphthoquinone	0.00 ± 0.00	30.08 ± 11.07	3.73 ± 5.27	3.81 ± 5.39	7.69 ± 0.02	0.00 ± 0.00	3.89 ± 5.50

Acenaphthenequinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylphenanthrene	37.25 ± 5.94	29.95 ± 4.84	100.69 ± 21.05	18.51 ± 20.79	19.23 ± 0.06	15.31 ± 16.25	17.78 ± 25.14
2-methylphenanthrene	24.00 ± 21.48	35.12 ± 15.36	143.21 ± 10.62	8.12 ± 11.48	36.15 ± 5.55	39.77 ± 21.73	44.91 ± 39.29
Perinaphthenone	53.98 ± 76.34	50.57 ± 43.20	53.72 ± 58.04	2.58 ± 3.65	47.61 ± 48.80	24.49 ± 27.09	64.09 ± 38.12
2-methylanthracene	9.42 ± 13.32	3.75 ± 0.06	11.19 ± 0.01	0.00 ± 0.00	5.78 ± 8.17	7.63 ± 5.38	1.95 ± 2.75
4,5-methylenephenanthrene	3.77 ± 5.33	11.21 ± 5.13	7.46 ± 0.00	0.00 ± 0.00	3.85 ± 5.45	3.81 ± 5.39	3.95 ± 5.59
9-methylphenanthrene	8.08 ± 11.43	27.70 ± 4.87	57.43 ± 5.25	0.76 ± 1.08	13.07 ± 5.40	1.53 ± 0.00	21.26 ± 16.86
1-methylphenanthrene	6.24 ± 8.83	21.14 ± 29.89	35.05 ± 10.53	5.25 ± 0.12	6.55 ± 9.26	2.68 ± 3.79	18.57 ± 26.26
Anthrone	33.62 ± 16.39	11.13 ± 15.73	52.23 ± 63.31	0.00 ± 0.00	0.00 ± 0.00	11.47 ± 5.44	11.85 ± 16.76
9-methylanthracene	6.24 ± 8.83	5.25 ± 0.08	5.22 ± 0.00	0.00 ± 0.00	2.69 ± 3.80	2.67 ± 3.77	0.00 ± 0.00
Anthraquinone	0.00 ± 0.00	3.71 ± 5.24	18.64 ± 26.36	0.00 ± 0.00	7.69 ± 0.02	0.00 ± 0.00	15.80 ± 22.35
A-dimethylphenanthrene	23.95 ± 16.22	9.04 ± 5.44	20.14 ± 0.01	12.87 ± 10.90	16.89 ± 16.26	2.68 ± 3.79	0.00 ± 0.00
B-dimethylphenanthrene	5.16 ± 5.17	0.00 ± 0.00	35.06 ± 36.94	0.76 ± 1.08	16.95 ± 21.80	46.51 ± 65.78	1.57 ± 0.02
1,7-dimethylphenanthrene	5.21 ± 0.09	9.04 ± 5.44	12.68 ± 10.54	2.58 ± 3.65	5.38 ± 0.02	5.35 ± 0.02	2.77 ± 3.91
3,6-dimethylphenanthrene	0.00 ± 0.00	3.79 ± 5.36	14.92 ± 0.01	3.69 ± 5.22	7.69 ± 0.02	0.00 ± 0.00	0.00 ± 0.00
D-dimethylphenanthrene	0.00 ± 0.00	3.75 ± 0.06	3.73 ± 0.00	0.00 ± 0.00	3.85 ± 0.01	1.91 ± 2.71	1.98 ± 2.79
E-dimethylphenanthrene	0.00 ± 0.00	3.79 ± 5.36	11.19 ± 5.28	0.00 ± 0.00	0.00 ± 0.00	7.64 ± 0.02	3.95 ± 5.59
C-dimethylphenanthrene	5.26 ± 5.36	20.45 ± 26.82	27.59 ± 15.81	0.74 ± 1.04	5.39 ± 5.45	0.77 ± 1.08	68.07 ± 26.99
Fluoranthene	7.39 ± 5.13	7.46 ± 5.19	16.79 ± 23.74	1.84 ± 2.61	3.85 ± 0.01	3.82 ± 0.01	11.82 ± 11.22
Pyrene	41.06 ± 16.53	22.50 ± 0.35	55.95 ± 26.40	22.26 ± 20.70	15.41 ± 21.80	15.28 ± 0.04	54.89 ± 0.59
9-Anthraaldehyde	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Retene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

benzo(a)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	3.89 ± 5.50
benzo(b)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	3.81 ± 5.39	0.00 ± 0.00
5-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.72 ± 3.85
1-MeFl+C-MeFl/Py	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.58 ± 3.65	0.00 ± 0.00	2.67 ± 3.77	2.72 ± 3.85
1+3-methylfluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.72 ± 3.85
4-methylpyrene	5.21 ± 0.09	0.00 ± 0.00	5.22 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.72 ± 3.85
C-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.67 ± 3.77	0.00 ± 0.00
D-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	2.61 ± 3.69	2.67 ± 3.77	2.70 ± 3.81	0.00 ± 0.00	2.77 ± 3.91
1-methylpyrene	1.84 ± 2.60	0.00 ± 0.00	0.00 ± 0.00	1.84 ± 2.61	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzonaphthothiophene	0.73 ± 1.04	0.74 ± 1.05	0.00 ± 0.00	0.74 ± 1.04	0.00 ± 0.00	1.53 ± 0.00	0.00 ± 0.00
benzo(c)phenanthrene	0.00 ± 0.00	1.90 ± 2.68	5.59 ± 7.91	1.84 ± 2.61	5.78 ± 8.17	5.72 ± 8.09	0.00 ± 0.00
Benzo(ghi)fluoranthene	1.88 ± 2.66	3.75 ± 0.06	1.86 ± 2.64	0.00 ± 0.00	3.85 ± 0.01	3.82 ± 0.01	11.82 ± 11.22
9-phenylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	3.69 ± 5.22	3.85 ± 5.45	0.00 ± 0.00	0.00 ± 0.00
6-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.58 ± 3.65	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benz(a)anthracene	5.21 ± 0.09	0.00 ± 0.00	0.00 ± 0.00	2.67 ± 3.77	0.00 ± 0.00	17.92 ± 25.34	17.28 ± 5.73
Chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzanthrone	7.44 ± 0.14	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	11.73 ± 5.42
Benz(a)anthracene-7,12-dione	0.00 ± 0.00	3.79 ± 5.36	3.73 ± 5.28	3.69 ± 5.22	3.84 ± 5.43	7.64 ± 0.02	0.00 ± 0.00
3-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

7,12-dimethylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	19.27 ± 27.25	0.00 ± 0.00	97.99 ± 4.49
Benzo(b)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(j)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(a)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BeP	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.58 ± 3.65	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BaP	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.84 ± 2.61	0.00 ± 0.00	1.91 ± 2.70	0.00 ± 0.00
Perylene	0.00 ± 0.00	5.56 ± 7.87	0.00 ± 0.00	0.00 ± 0.00	7.68 ± 5.41	0.00 ± 0.00	1.98 ± 2.79
3-methylcholanthrene	0.00 ± 0.00	1.50 ± 0.02	5.22 ± 5.27	0.74 ± 1.04	1.54 ± 0.00	0.76 ± 1.08	1.57 ± 0.02
7-methylbenzo(a)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	20.54 ± 29.05
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00 ± 0.00	5.25 ± 0.08	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]fluoranthene	0.00 ± 0.00	0.00 ± 0.00	3.73 ± 5.27	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]pyrene	74.40 ± 1.35	74.99 ± 1.16	74.59 ± 0.04	75.00 ± 1.72	76.90 ± 0.23	76.41 ± 0.22	78.42 ± 0.84
Dibenzo(ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah+ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	3.84 ± 5.43	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Picene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	10.36 ± 14.65	0.00 ± 0.00	0.00 ± 0.00
Benzo(ghi)perylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.67 ± 3.77	0.00 ± 0.00	2.67 ± 3.77	0.00 ± 0.00
Anthanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.67 ± 3.77	0.00 ± 0.00

Triphenylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,l)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,e)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table D3: Gas-phase PAH emission for Vehicle #3

Component (ng/mile)	Fed ULSD	CARB USLD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Naphthalene	823.96 ± 419.22	387.93 ± 121.85	3488.89 ± 3193.02	1039.17 ± 409.74	3292.82 ± 2589.81	875.97 ± 54.04	1426.98 ± 116.00
Quinoline	9.55 ± 5.33	6.01 ± 5.18	74.58 ± 47.30	11.24 ± 7.28	23.18 ± 4.68	7.97 ± 2.38	14.52 ± 2.55
2-methylnaphthalene	235.73 ± 71.40	181.54 ± 21.05	564.60 ± 368.44	269.55 ± 79.76	494.72 ± 120.29	301.71 ± 10.90	464.64 ± 1.30
1-methylnaphthalene	141.39 ± 74.98	103.67 ± 14.83	721.23 ± 721.68	202.09 ± 113.54	619.41 ± 491.39	167.09 ± 16.64	245.21 ± 17.65
Biphenyl	83.80 ± 80.06	41.42 ± 7.90	102.01 ± 34.88	65.21 ± 16.23	81.43 ± 8.11	78.42 ± 19.85	102.00 ± 22.77
2-methylbiphenyl	3056.73 ± 1887.21	2056.89 ± 460.17	2232.53 ± 837.08	3096.34 ± 22.20	1392.21 ± 175.59	1296.70 ± 1041.10	2144.47 ± 502.68
2,6+2,7-dimethylnaphthalene	94.89 ± 23.64	44.89 ± 7.74	100.23 ± 2.42	104.43 ± 19.50	161.32 ± 57.83	133.05 ± 26.27	174.51 ± 13.56
1,3+1,6+1,7dimethylnaphth	159.49 ± 70.77	83.54 ± 15.76	269.79 ± 112.09	173.74 ± 11.64	335.09 ± 34.96	190.00 ± 14.76	271.80 ± 19.88
1,4+1,5+2,3-dimethylnaphth	46.65 ± 24.15	28.40 ± 1.14	122.08 ± 104.53	64.25 ± 6.26	127.05 ± 13.51	57.23 ± 11.63	90.47 ± 11.51
Acenaphthylene	14.35 ± 17.89	5.09 ± 4.67	8.79 ± 4.97	10.58 ± 2.29	12.08 ± 9.68	9.03 ± 4.93	19.06 ± 14.80
1,2-dimethylnaphthalene	7.00 ± 0.28	3.36 ± 4.75	22.86 ± 12.45	5.23 ± 7.40	15.64 ± 12.39	12.70 ± 2.27	20.73 ± 0.16
1,8-dimethylnaphthalene	1.70 ± 2.40	0.00 ± 0.00	1.76 ± 2.49	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Acenaphthene	5.95 ± 0.24	30.08 ± 3.52	30.60 ± 0.02	3.05 ± 4.31	47.50 ± 10.24	31.65 ± 0.74	45.57 ± 6.98
3-methylbiphenyl	1647.34 ± 1016.44	1655.34 ± 412.23	1859.53 ± 247.44	1859.82 ± 45.84	1678.24 ± 114.15	1182.64 ± 619.27	1351.92 ± 127.70
4-methylbiphenyl	743.27 ± 440.66	776.16 ± 204.96	838.86 ± 152.26	765.28 ± 27.24	685.53 ± 52.38	612.63 ± 142.99	832.84 ± 74.83
1+2ethylnaphthalene	38.05 ± 31.22	16.20 ± 4.16	41.15 ± 9.97	32.39 ± 11.87	35.39 ± 12.58	37.01 ± 6.84	56.03 ± 17.53
1-ethyl-2-methylnaphthalene	125.14 ± 49.59	73.51 ± 30.36	102.00 ± 17.48	127.40 ± 19.95	119.54 ± 10.91	72.90 ± 14.57	127.87 ± 13.20
2,3,5+I-trimethylnaphthalene	49.25 ± 14.37	10.24 ± 6.88	56.27 ± 17.37	42.63 ± 23.31	117.89 ± 28.04	76.42 ± 4.37	79.49 ± 7.94
B-trimethylnaphthalene	66.00 ± 29.88	22.63 ± 25.92	69.28 ± 7.41	71.83 ± 46.36	125.66 ± 59.95	80.94 ± 17.33	104.31 ± 4.08
A-trimethylnaphthalene	87.09 ± 35.68	24.88 ± 3.76	67.52 ± 9.90	78.94 ± 51.49	149.91 ± 60.18	86.18 ± 0.54	133.71 ± 3.48
C-trimethylnaphthalene	69.50 ± 30.02	24.88 ± 3.76	62.25 ± 7.50	66.26 ± 18.77	108.25 ± 40.20	88.21 ± 17.50	107.80 ± 5.72
2-ethyl-1-methylnaphthalene	0.70 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.44 ± 2.47	2.52 ± 2.51	0.00 ± 0.00
E-trimethylnaphthalene	37.15 ± 21.29	17.18 ± 6.56	52.76 ± 2.52	47.86 ± 15.91	83.19 ± 13.02	49.17 ± 6.30	63.93 ± 5.38
2,4,5-trimethylnaphthalene	4.25 ± 2.65	4.84 ± 6.84	10.03 ± 14.18	11.38 ± 7.72	30.16 ± 5.18	19.01 ± 8.16	45.59 ± 2.09
F-trimethylnaphthalene	39.45 ± 13.97	10.94 ± 6.85	46.42 ± 2.46	37.96 ± 15.72	63.12 ± 17.73	48.05 ± 3.70	61.19 ± 10.24
Fluorene	80.05 ± 67.54	105.86 ± 4.88	121.33 ± 9.87	40.93 ± 30.77	180.15 ± 9.03	124.07 ± 36.35	179.67 ± 8.72
1,4,5-trimethylnaphthalene	5.90 ± 2.23	0.69 ± 0.03	2.46 ± 2.49	4.24 ± 0.08	37.30 ± 51.78	8.00 ± 0.19	12.81 ± 7.43
J-trimethylnaphthalene	70.10 ± 59.72	4.16 ± 0.19	9.50 ± 2.49	7.78 ± 0.15	45.99 ± 59.21	8.06 ± 5.33	11.05 ± 0.09
A-Methylfluorene	5.40 ± 7.64	0.00 ± 0.00	17.58 ± 9.94	3.53 ± 0.07	19.08 ± 7.53	23.61 ± 2.02	22.43 ± 7.15
B-Methylfluorene	2.45 ± 0.10	9.60 ± 10.25	2.46 ± 0.00	0.00 ± 0.00	2.42 ± 0.02	4.40 ± 2.67	7.57 ± 7.27
1-Methylfluorene	3.50 ± 0.14	0.00 ± 0.00	1.76 ± 2.49	0.00 ± 0.00	5.18 ± 2.40	3.58 ± 5.06	6.91 ± 0.05
9-fluorenone	49.70 ± 36.64	46.91 ± 4.62	66.83 ± 19.94	12.54 ± 17.73	95.22 ± 6.46	118.62 ± 36.22	140.00 ± 23.07
Dibenzothiophene	1.75 ± 0.07	2.52 ± 3.56	7.03 ± 2.48	1.77 ± 0.03	12.15 ± 5.01	16.49 ± 10.67	13.83 ± 2.55
Phenanthrene	190.10 ± 200.59	67.87 ± 18.93	123.80 ± 4.89	50.38 ± 20.96	154.86 ± 8.79	139.14 ± 18.70	237.40 ± 18.93

Anthracene	8.80 ± 2.83	1.79 ± 2.53	1.76 ± 2.49	1.79 ± 2.53	10.39 ± 0.10	9.18 ± 7.93	25.94 ± 7.53
Xanthone	1.75 ± 0.07	5.88 ± 8.31	22.86 ± 4.96	4.48 ± 6.33	41.58 ± 2.84	21.92 ± 8.23	86.38 ± 3.11
1,4-Naphthoquinone	1.19 ± 1.68	9.37 ± 0.43	13.02 ± 9.96	11.29 ± 2.28	11.07 ± 2.35	11.73 ± 7.99	7.57 ± 7.27
Acenaphthenequinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylphenanthrene	19.60 ± 18.10	8.39 ± 11.87	12.31 ± 2.50	5.28 ± 2.40	20.76 ± 4.70	18.25 ± 5.57	29.36 ± 2.22
2-methylphenanthrene	31.80 ± 16.13	10.30 ± 4.43	24.62 ± 0.02	14.19 ± 5.27	34.64 ± 0.32	10.73 ± 15.18	34.55 ± 0.27
Perinaphthenone	9.50 ± 2.86	0.00 ± 0.00	2.11 ± 2.98	2.09 ± 2.96	14.55 ± 0.14	9.85 ± 2.80	14.57 ± 14.77
2-methylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.72 ± 2.43
4,5-methylenephenanthrene	6.66 ± 9.42	1.18 ± 1.66	2.99 ± 4.23	0.00 ± 0.00	4.17 ± 2.49	7.91 ± 7.53	11.05 ± 2.36
9-methylphenanthrene	12.50 ± 12.87	10.30 ± 4.43	8.79 ± 2.48	0.00 ± 0.00	13.81 ± 9.67	10.79 ± 10.03	22.46 ± 2.62
1-methylphenanthrene	19.65 ± 20.58	5.21 ± 0.24	14.07 ± 2.48	0.87 ± 1.23	8.61 ± 9.72	9.03 ± 4.93	15.51 ± 9.65
Anthrone	0.70 ± 0.03	2.37 ± 2.34	11.25 ± 9.94	9.52 ± 2.32	2.41 ± 2.43	4.37 ± 0.10	7.60 ± 0.06
9-methylanthracene	1.26 ± 1.78	2.43 ± 0.11	2.46 ± 0.00	1.22 ± 1.73	4.14 ± 2.41	2.55 ± 0.06	0.00 ± 0.00
Anthraquinone	0.00 ± 0.00	0.00 ± 0.00	7.03 ± 0.00	0.00 ± 0.00	3.44 ± 4.87	19.98 ± 2.10	6.93 ± 4.94
A-dimethylphenanthrene	0.90 ± 1.27	0.00 ± 0.00	0.88 ± 1.24	0.90 ± 1.27	0.00 ± 0.00	4.62 ± 6.54	5.16 ± 4.85
B-dimethylphenanthrene	12.35 ± 5.45	10.24 ± 6.88	15.82 ± 9.94	10.58 ± 2.29	15.59 ± 0.15	18.28 ± 8.14	20.70 ± 7.17
1,7-dimethylphenanthrene	7.80 ± 5.26	0.69 ± 0.03	7.74 ± 4.97	2.50 ± 2.55	4.13 ± 4.86	4.37 ± 0.10	9.34 ± 2.51
3,6-dimethylphenanthrene	1.75 ± 0.07	0.84 ± 1.19	1.76 ± 0.00	0.90 ± 1.27	1.73 ± 0.02	3.67 ± 2.66	3.45 ± 2.42
D-dimethylphenanthrene	3.55 ± 2.62	1.74 ± 0.08	1.76 ± 0.00	1.77 ± 0.03	2.58 ± 3.65	5.52 ± 5.27	5.18 ± 0.04
E-dimethylphenanthrene	0.36 ± 0.51	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.34 ± 0.49	0.37 ± 0.52	2.41 ± 2.42
C-dimethylphenanthrene	11.30 ± 5.40	4.16 ± 0.19	7.74 ± 4.97	5.98 ± 2.38	9.32 ± 7.26	6.27 ± 7.86	12.77 ± 2.34
Fluoranthene	16.80 ± 17.99	10.99 ± 4.40	13.01 ± 2.48	2.50 ± 2.55	19.73 ± 2.27	13.43 ± 2.26	33.50 ± 2.18

Pyrene	15.66 ± 22.15	5.79 ± 4.64	21.80 ± 2.47	1.25 ± 1.77	31.83 ± 7.05	17.10 ± 0.40	35.27 ± 7.60
9-Anthraaldehyde	0.00 ± 0.00	5.15 ± 2.21	14.07 ± 4.96	0.00 ± 0.00	24.41 ± 34.51	8.94 ± 12.65	20.69 ± 9.61
Retene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(a)fluorene	0.00 ± 0.00	1.79 ± 2.53	0.00 ± 0.00	0.00 ± 0.00	1.72 ± 2.43	3.64 ± 0.09	1.72 ± 2.43
benzo(b)fluorene	0.00 ± 0.00	0.00 ± 0.00	1.76 ± 2.49	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
5-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	1.76 ± 2.49	0.00 ± 0.00	1.72 ± 2.43	3.64 ± 0.09	0.00 ± 0.00
1-MeFl+C-MeFl/Py	0.00 ± 0.00	0.00 ± 0.00	1.76 ± 2.49	0.00 ± 0.00	1.72 ± 2.43	3.64 ± 0.09	1.72 ± 2.43
1+3-methylfluoranthene	0.85 ± 1.20	1.74 ± 0.08	0.88 ± 1.24	0.00 ± 0.00	1.73 ± 0.02	0.89 ± 1.26	0.00 ± 0.00
4-methylpyrene	2.45 ± 0.10	0.00 ± 0.00	1.23 ± 1.74	1.22 ± 1.73	2.42 ± 0.02	2.55 ± 0.06	1.20 ± 1.70
C-MePy/MeFl	1.26 ± 1.78	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.22 ± 1.73	2.55 ± 0.06	1.20 ± 1.70
D-MePy/MeFl	1.26 ± 1.78	1.25 ± 1.77	0.00 ± 0.00	0.00 ± 0.00	1.22 ± 1.73	2.55 ± 0.06	2.42 ± 0.02
1-methylpyrene	1.80 ± 2.55	0.00 ± 0.00	1.76 ± 2.49	0.00 ± 0.00	3.46 ± 0.03	1.85 ± 2.61	1.72 ± 2.43
Benzonaphthothiophene	0.00 ± 0.00	0.69 ± 0.03	0.70 ± 0.00	0.71 ± 0.01	2.41 ± 2.43	0.73 ± 0.02	0.35 ± 0.49
benzo(c)phenanthrene	0.90 ± 1.27	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.73 ± 0.02	0.92 ± 1.31	0.00 ± 0.00
Benzo(ghi)fluoranthene	1.19 ± 1.68	1.18 ± 1.66	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
9-phenylanthracene	1.80 ± 2.55	0.00 ± 0.00	0.00 ± 0.00	1.79 ± 2.53	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
6-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzanthrone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.36 ± 0.51	0.00 ± 0.00	0.36 ± 0.51	0.69 ± 0.01

Benz(a)anthracene-7,12-dione	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7,12-dimethylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(j)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(a)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BeP	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BaP	1.26 ± 1.78	2.43 ± 0.11	1.23 ± 1.74	2.47 ± 0.05	4.17 ± 2.49	0.00 ± 0.00	0.00 ± 0.00
Perylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.74 ± 2.47	0.00 ± 0.00	0.00 ± 0.00
3-methylcholanthrene	1.80 ± 2.55	3.47 ± 0.16	1.76 ± 2.49	1.74 ± 2.47	1.72 ± 2.43	3.64 ± 0.09	3.45 ± 0.03
7-methylbenzo(a)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah+ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Picene	0.70 ± 0.03	0.69 ± 0.03	0.70 ± 0.00	0.35 ± 0.49	0.69 ± 0.01	0.00 ± 0.00	0.69 ± 0.01
Benzo(ghi)perylene	0.00 ± 0.00	0.00 ± 0.00	0.35 ± 0.50	0.00 ± 0.00	4.16 ± 0.04	0.73 ± 0.02	0.69 ± 0.01
Anthanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Triphenylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,l)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,e)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table D4: Gas-phase PAH emission for Vehicle #4

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	1447.17±1866.22	334.08±195.24	675.83±678.01	2136.79±1725.48	2635.87±2925.23	3803.23±1059.94	2460.21±2823.80
quinoline	1.32±1.11	1.05±0.73	2.63±2.98	2.83±3.27	31.47±43.01	2.59±2.92	0.26±0.37
2-methylnaphthalene	83.93±62.04	113.32±58.37	76.05±19.05	185.64±31.36	134.60±0.00	36.53±2.56	74.53±1.85
1-methylnaphthalene	46.04±36.04	50.91±22.55	38.15±10.08	96.54±22.05	67.04±0.00	20.61±1.62	38.71±4.84
Biphenyl	93.88±122.33	33.61±10.07	25.78±2.26	76.87±44.78	817.20±1107.18	35.45±8.48	28.71±12.29
2,6+2,7-dimethylnaphthalene	37.35±39.40	65.28±42.11	36.84±10.45	72.77±36.76	67.04±0.00	14.08±3.54	30.29±3.36
1,3+1,6+1,7dimethylnaphth	50.50±51.30	98.83±63.35	54.47±13.82	115.51±57.06	103.46±0.00	21.65±3.09	44.77±4.47
1,4+1,5+2,3-dimethylnaphth	18.41±19.33	35.39±23.07	18.68±4.86	36.79±17.09	41.17±0.00	9.15±1.94	19.23±0.37
Acenaphthylene	5.26±3.71	6.04±1.80	2.89±0.37	8.34±2.33	50.12±56.69	1.04±0.01	7.11±3.35
1,2-dimethylnaphthalene	9.73±10.78	16.77±11.73	8.68±0.38	15.04±5.65	17.95±0.00	3.13±0.03	8.16±1.86
1,8-dimethylnaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Acenaphthene	87.04±118.62	23.84±17.98	15.52±4.11	23.69±4.41	40.12±0.00	5.21±1.42	21.33±0.37
1+2ethylnaphthalene	259.28±358.47	25.97±14.24	18.42±4.48	42.05±8.92	47.51±0.00	7.04±1.03	42.40±8.56
1-ethyl-2-methylnaphthalene	11.57±12.64	13.11±8.05	7.10±2.61	13.75±3.83	13.72±0.00	7.07±4.88	7.37±0.74

2,3,5+I-trimethylnaphthalene	39.45±50.57	60.49±51.83	26.58±9.33	33.18±11.99	50.67±0.00	8.87±0.64	24.49±0.38
B-trimethylnaphthalene	21.83±24.16	56.59±44.06	23.95±11.56	38.87±17.05	48.03±0.00	9.65±1.00	19.23±3.35
A-trimethylnaphthalene	29.72±33.83	58.96±42.92	30.52±9.70	52.31±27.14	62.81±0.00	13.31±0.96	29.76±7.07
C-trimethylnaphthalene	22.09±26.03	58.42±45.90	24.47±7.09	36.55±14.52	47.51±0.00	8.08±1.76	17.65±4.10
2-ethyl-1-methylnaphthalene	0.79±1.12	1.31±1.10	0.53±0.00	1.30±0.35	11.02±14.83	0.26±0.37	0.53±0.74
E-trimethylnaphthalene	36.03±46.48	37.99±29.74	19.74±5.60	23.85±9.19	35.37±0.00	5.74±0.06	14.75±2.24
2,4,5-trimethylnaphthalene	122.02±162.87	99.50±86.77	23.15±3.00	61.51±13.40	93.43±0.00	20.82±11.59	25.02±1.86
F-trimethylnaphthalene	27.35±34.95	39.81±32.33	16.84±5.97	20.74±7.77	32.73±0.00	5.74±0.68	13.17±2.24
Fluorene	46.81±55.77	91.34±88.72	48.15±15.30	50.12±6.95	87.62±0.00	13.57±1.33	30.81±4.10
1,4,5-trimethylnaphthalene	12.88±18.22	17.04±11.36	4.74±2.98	1.30±0.35	91.56±112.31	3.37±4.02	2.11±0.75
J-trimethylnaphthalene	9.20±12.27	10.73±11.42	8.42±5.96	4.92±2.50	20.59±0.00	2.62±1.50	3.42±0.37
A-Methylfluorene	22.09±25.28	32.73±29.05	19.73±4.86	25.35±16.52	35.37±0.00	4.19±2.26	11.59±7.45
B-Methylfluorene	3.94±5.58	6.03±4.77	7.36±5.20	20.09±23.96	118.54±159.44	42.28±1.02	1.84±1.86
1-Methylfluorene	10.26±11.52	14.68±10.27	8.42±2.24	44.56±54.10	24.17±14.77	66.02±2.61	11.85±6.33
9-fluorenone	173.83±216.02	31.17±24.61	13.95±4.85	46.51±36.79	27.98±0.00	13.10±9.00	18.96±2.23
Dibenzothiophene	9.73±10.04	14.64±17.71	5.00±3.35	3.37±1.05	3.69±0.00	4.72±4.48	7.90±0.75
Phenanthrene	163.09±154.61	247.33±240.38	112.63±38.06	179.10±138.81	245.97±0.00	42.60±9.69	110.35±8.58
Anthracene	5.00±5.58	8.12±6.24	4.74±0.75	8.30±2.81	6.33±0.00	2.61±0.77	3.95±0.37
Xanthone	7.10±6.32	5.23±5.15	2.89±0.37	6.98±4.67	6.86±0.00	3.67±3.73	3.42±1.86
1,4-Naphthoquinone	41.29±56.15	1.85±1.13	1.84±1.86	11.76±8.64	33.73±25.45	15.25±20.10	38.45±28.30
Acenaphthenequinone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-methylphenanthrene	26.30±29.74	29.58±26.85	12.89±3.36	25.38±12.11	38.53±0.00	17.56±13.11	30.81±1.87
2-methylphenanthrene	17.89±19.33	29.81±33.92	12.10±2.99	19.10±18.09	35.37±0.00	12.60±12.69	15.80±0.00
Perinaphthenone	2.89±3.35	2.89±1.09	0.53±0.74	3.09±4.36	5.28±0.00	25.49±30.91	2.11±1.49
2-methylanthracene	13.94±19.71	14.89±20.31	10.52±2.97	8.62±4.91	26.39±0.00	4.97±1.16	3.69±2.98
4,5-methylenephenanthrene	7.89±8.92	5.50±4.78	3.68±0.75	4.40±2.51	8.45±0.00	5.75±1.54	2.63±0.00
9-methylphenanthrene	10.78±10.78	15.69±16.95	7.10±0.38	13.68±13.39	17.42±0.00	17.34±20.12	10.80±4.84
1-methylphenanthrene	7.10±6.32	11.24±12.90	5.00±1.87	8.52±7.59	14.25±0.00	10.50±11.19	5.27±2.24
Anthrone	124.12±171.80	11.51±11.79	2.37±0.37	6.50±0.47	8.45±0.00	21.26±22.01	17.38±2.24
9-methylanthracene	14.20±20.08	0.52±0.74	0.26±0.37	0.00±0.00	29.11±40.42	0.52±0.01	0.79±0.37

Anthraquinone	23.41±28.63	15.96±15.83	7.10±1.12	28.11±30.09	33.63±17.70	13.85±2.73	14.48±1.86
A-dimethylphenanthrene	2.89±3.35	6.02±6.26	2.10±0.00	11.58±15.63	45.13±52.62	18.01±0.17	1.84±0.37
B-dimethylphenanthrene	2.89±3.35	5.23±5.90	2.89±1.86	12.87±16.72	55.61±69.69	9.99±12.66	1.32±0.37
1,7-dimethylphenanthrene	3.16±3.72	5.23±5.90	3.68±2.23	11.85±14.53	29.65±32.23	20.37±1.70	2.63±0.00
3,6-dimethylphenanthrene	3.68±4.46	5.23±6.64	1.05±0.75	4.93±1.03	59.54±78.97	4.99±6.33	5.79±4.47
D-dimethylphenanthrene	14.73±18.59	19.37±17.66	5.53±4.10	8.31±0.61	63.77±66.30	20.99±20.16	3.69±0.00
E-dimethylphenanthrene	0.53±0.74	2.09±2.21	1.05±0.00	1.81±1.81	53.78±67.09	8.41±10.43	3.16±0.74
C-dimethylphenanthrene	9.73±12.27	9.94±11.06	4.47±0.37	8.53±6.86	67.18±74.85	21.29±27.92	6.58±0.37
Fluoranthene	16.58±9.28	22.76±24.69	11.05±2.99	26.58±25.70	127.26±143.40	14.68±11.97	11.85±0.37
Pyrene	17.88±20.82	24.05±29.51	8.42±0.75	14.45±14.49	79.80±74.04	10.50±11.19	12.90±0.37
9-Anthraaldehyde	4.21±5.21	0.78±1.11	1.05±1.49	1.30±0.35	0.00±0.00	6.01±1.91	1.84±1.12
Retene	0.00±0.00	0.26±0.37	0.00±0.00	0.26±0.36	0.26±0.37	0.79±1.12	0.00±0.00
benzo(a)fluorene	0.53±0.74	0.26±0.37	0.00±0.00	0.51±0.73	0.00±0.00	0.52±0.01	0.26±0.37
benzo(b)fluorene	1.58±2.23	0.00±0.00	0.26±0.37	1.29±1.08	0.00±0.00	0.78±0.36	0.79±1.12
5-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
B-MePy/MeFl	1.05±0.74	0.26±0.37	0.26±0.37	1.55±1.45	0.26±0.37	1.31±0.38	0.26±0.37
1-MeFl+C-MeFl/Py	0.53±0.00	0.79±0.36	0.26±0.37	13.37±18.91	0.00±0.00	4.94±4.01	1.84±0.37
1+3-methylfluoranthene	1.84±1.86	0.26±0.37	0.26±0.37	1.55±1.45	0.26±0.37	1.04±0.01	1.05±0.74
4-methylpyrene	1.31±1.86	0.78±1.11	0.26±0.37	1.03±0.72	1.06±1.49	1.84±2.60	1.05±0.00
C-MePy/MeFl	3.16±4.46	0.26±0.37	0.26±0.37	2.06±2.17	0.00±0.00	2.08±0.72	1.58±1.49
D-MePy/MeFl	2.37±2.60	2.10±1.47	1.58±2.23	8.24±10.17	1.06±1.49	17.47±2.39	2.90±1.12
1-methylpyrene	1.84±1.86	0.52±0.74	0.26±0.37	1.03±0.72	0.53±0.75	5.98±4.00	0.53±0.00
Benzonaphthothiophene	1.58±1.49	0.52±0.74	0.00±0.00	9.28±10.89	1.06±1.49	5.73±2.15	0.00±0.00
benzo(c)phenanthrene	0.26±0.37	0.00±0.00	0.00±0.00	0.26±0.37	0.26±0.37	0.26±0.37	0.00±0.00
Benzo(ghi)fluoranthene	5.79±7.44	0.78±1.11	2.63±2.23	1.03±0.72	0.00±0.00	8.14±9.32	0.26±0.37
9-phenylanthracene	0.26±0.37	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37	0.00±0.00
6-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Cyclopenta(c,d)pyrene	0.79±1.12	0.00±0.00	0.26±0.37	0.78±0.36	0.00±0.00	0.00±0.00	0.00±0.00
Benz(a)anthracene	0.79±1.12	0.00±0.00	0.00±0.00	0.26±0.36	0.00±0.00	0.00±0.00	0.00±0.00
Chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Benzanthrone	1.58±1.49	0.78±1.11	0.26±0.37	1.54±2.18	0.00±0.00	1.58±2.23	0.26±0.37
Benz(a)anthracene-7,12-dione	7.10±9.30	0.26±0.37	0.53±0.00	0.26±0.37	0.00±0.00	2.37±3.35	0.00±0.00
3-methylchrysene	0.26±0.37	0.26±0.37	0.00±0.00	0.26±0.36	0.00±0.00	0.00±0.00	0.00±0.00
7-methylbenz(a)anthracene	1.58±2.23	0.00±0.00	0.00±0.00	0.51±0.73	0.26±0.37	0.00±0.00	0.00±0.00
7,12-dimethylbenz(a)anthracene	1.58±2.23	0.26±0.37	0.26±0.37	0.51±0.73	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(b)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(j)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(a)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37
BeP	0.00±0.00	0.00±0.00	0.00±0.00	0.52±0.01	0.00±0.00	0.00±0.00	0.00±0.00
BaP	0.26±0.37	0.00±0.00	0.26±0.37	0.26±0.37	0.00±0.00	0.52±0.73	1.05±1.49
Perylene	0.26±0.37	0.00±0.00	#DIV/0!	0.00±0.00	0.00±0.00	0.52±0.73	0.26±0.37
3-methylcholanthrene	0.00±0.00	0.52±0.74	0.26±0.37	0.00±0.00	0.00±0.00	0.26±0.37	0.00±0.00
7-methylbenzo(a)pyrene	0.00±0.00	0.26±0.37	0.26±0.37	0.00±0.00	0.26±0.37	0.00±0.00	0.26±0.37
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00±0.00	0.00±0.00	0.26±0.37	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Indeno[123-cd]fluoranthene	0.00±0.00	0.00±0.00	0.53±0.74	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Indeno[123-cd]pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah+ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,j)anthracene	0.00±0.00	0.26±0.37	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(b)chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.53±0.74
Picene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(ghi)perylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Anthanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Triphenylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,l)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Coronene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,e)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Dibenzo(a,i)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,h)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(b,k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D5: Gas-phase PAH emission for Vehicle #5

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	29596.39±7676.97	1279.59±1588.50	3271.05±0.00	1048.78±0.00	3133.46±3294.43	3557.51±1185.15	3752.19±2570.61
quinoline	206.38±8.00	7.12±7.23	24.50±0.00	120.51±146.61	3.05±1.44	20.80±3.86	30.48±32.53
2-methylnaphthalene	2477.30±688.41	84.54±29.27	327.00±0.00	108.49±0.00	85.04±14.05	131.93±42.61	461.19±145.60
1-methylnaphthalene	2054.22±662.96	51.10±25.34	236.15±0.00	75.80±0.00	59.66±16.19	75.44±24.94	244.46±65.29
Biphenyl	378.91±46.46	27.03±0.16	92.89±0.00	173.38±198.95	39.09±10.03	100.57±69.16	175.73±92.97
2,6+2,7-dimethylnaphthalene	235.03±19.05	31.97±2.55	89.22±0.00	90.88±73.17	31.22±4.68	55.36±14.63	178.52±102.62
1,3+1,6+1,7dimethylnaphth	405.42±36.05	49.57±3.27	139.13±0.00	176.52±160.66	49.25±7.21	97.32±32.72	279.89±123.96
1,4+1,5+2,3-dimethylnaphth	118.02±8.08	15.86±1.80	47.14±0.00	58.03±51.94	17.52±1.80	32.52±10.54	89.65±44.72
Acenaphthylene	5.10±2.13	1.49±0.03	5.81±0.00	3.45±0.73	5.08±3.59	4.49±0.16	39.04±31.67
1,2-dimethylnaphthalene	45.46±1.05	5.95±0.59	22.07±0.00	25.70±24.44	14.47±9.70	12.54±4.72	35.20±21.24
1,8-dimethylnaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Acenaphthene	104.32±32.54	7.94±0.85	29.34±0.00	19.66±3.28	31.72±19.73	84.26±94.56	133.19±131.98
1+2ethylnaphthalene	498.37±30.72	15.60±2.16	63.47±0.00	93.68±102.36	24.12±7.55	252.17±313.94	329.74±369.28
1-ethyl-2-methylnaphthalene	35.30±16.15	5.95±0.59	13.42±0.00	14.70±10.98	7.11±1.44	10.54±1.74	37.69±29.05
2,3,5+I-trimethylnaphthalene	65.29±45.62	17.12±0.67	69.76±0.00	29.50±3.18	27.92±1.45	35.04±5.42	135.13±99.77
B-trimethylnaphthalene	73.48±50.74	16.83±3.19	61.86±0.00	32.91±9.41	25.38±4.32	35.57±5.45	120.17±65.77
A-trimethylnaphthalene	123.59±64.83	23.06±0.62	65.37±0.00	41.73±16.28	26.65±6.12	44.10±8.10	142.54±93.83
C-trimethylnaphthalene	66.59±53.22	18.85±0.36	61.63±0.00	28.50±5.28	25.64±4.68	33.91±2.38	115.80±67.43
2-ethyl-1-methylnaphthalene	1.02±0.01	0.50±0.01	0.76±0.00	0.98±0.69	0.51±0.72	1.31±0.31	3.41±1.97
E-trimethylnaphthalene	47.62±32.13	11.91±0.23	41.33±0.00	21.12±5.35	17.01±3.24	26.09±7.24	80.00±55.34
2,4,5-trimethylnaphthalene	55.10±51.33	9.96±4.40	68.62±0.00	22.47±17.27	5.58±0.00	8.53±2.65	19.35±7.39
F-trimethylnaphthalene	44.04±29.94	11.41±0.22	47.45±0.00	18.68±1.90	20.31±2.14	23.10±3.73	78.99±56.77
Fluorene	75.05±60.14	19.30±4.55	108.51±0.00	49.41±4.72	44.93±6.13	48.26±5.31	181.40±116.68
1,4,5-trimethylnaphthalene	14.36±15.27	2.22±1.71	19.77±0.00	7.88±1.47	5.84±0.36	24.17±15.37	41.14±32.49

J-trimethylnaphthalene	28.16±18.99	5.92±3.40	28.17±0.00	10.33±0.59	13.20±2.16	15.94±3.01	53.19±38.11
A-Methylfluorene	36.32±15.43	12.65±0.59	39.26±0.00	20.89±2.92	15.99±12.57	19.39±3.55	80.80±69.32
B-Methylfluorene	6.65±2.22	1.99±0.74	7.08±0.00	3.69±0.38	31.46±39.47	2.06±2.14	16.23±7.26
1-Methylfluorene	21.49±10.27	7.44±0.14	18.99±0.00	8.86±0.78	45.93±46.28	7.85±3.36	17.91±12.49
9-fluorenone	98.48±42.25	13.15±0.60	33.73±0.00	16.70±4.70	15.99±1.80	212.37±231.61	258.05±250.05
Dibenzothiophene	11.75±1.53	4.23±1.13	10.66±0.00	2.71±1.77	5.33±0.36	3.72±0.93	34.18±34.77
Phenanthrene	265.05±129.06	70.52±9.05	310.25±0.00	107.44±6.92	128.70±6.89	247.92±103.91	607.36±380.86
Anthracene	8.19±5.84	2.24±0.39	11.17±0.00	4.42±0.65	6.09±4.31	9.07±3.43	21.25±11.50
Xanthone	11.00±4.05	2.48±0.05	8.62±0.00	3.44±0.03	3.81±1.07	8.25±2.27	24.57±9.07
1,4-Naphthoquinone	31.34±21.08	2.73±0.40	6.69±0.00	32.09±26.46	0.00±0.00	3.33±4.70	7.98±9.86
Acenaphthenequinone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-methylphenanthrene	107.82±13.07	8.93±0.17	37.56±0.00	15.97±3.67	20.82±3.60	35.16±21.51	122.58±120.55
2-methylphenanthrene	23.04±15.34	7.70±1.20	45.22±0.00	13.03±0.22	17.26±1.45	21.38±9.25	66.79±56.64
Perinaphthenone	3.85±5.45	0.75±0.36	6.32±0.00	3.20±1.08	2.28±1.08	8.38±7.51	7.17±8.00
2-methylanthracene	3.32±0.34	1.71±2.42	7.40±0.00	5.37±7.60	12.44±6.83	22.55±13.80	43.67±29.65
4,5-methylenephenanthrene	8.71±7.29	2.73±0.40	5.31±0.00	3.69±0.31	7.61±2.15	5.00±0.88	27.97±23.15
9-methylphenanthrene	14.32±5.16	4.96±0.09	21.85±0.00	7.12±1.67	14.47±9.68	12.78±3.61	36.27±22.75
1-methylphenanthrene	11.01±7.66	3.47±0.07	15.98±0.00	5.66±0.40	5.84±1.79	9.86±3.09	28.66±18.40
Anthrone	61.52±62.57	2.26±2.50	9.43±0.00	4.16±5.18	7.11±5.74	11.38±0.17	50.80±61.13
9-methylanthracene	1.03±1.45	0.25±0.36	0.76±0.00	0.74±0.34	0.76±0.36	1.06±0.05	2.91±2.69
Anthraquinone	129.02±152.99	15.79±8.82	54.18±0.00	10.33±0.80	115.53±137.55	63.76±42.94	77.69±56.35
A-dimethylphenanthrene	7.41±1.14	1.24±0.37	7.62±0.00	2.70±1.02	3.55±0.72	6.26±3.44	13.39±7.51
B-dimethylphenanthrene	3.07±2.19	0.99±0.02	5.85±0.00	1.23±0.36	8.37±8.25	2.14±0.85	9.51±8.46
1,7-dimethylphenanthrene	3.33±1.83	1.24±0.33	6.60±0.00	1.97±0.02	2.79±1.08	2.15±1.60	10.82±8.88
3,6-dimethylphenanthrene	3.84±1.83	1.24±0.37	5.59±0.00	1.48±0.01	2.03±0.72	2.41±1.24	12.61±7.85
D-dimethylphenanthrene	10.23±4.41	4.48±2.19	11.16±0.00	3.21±1.77	15.48±17.58	3.18±0.15	14.42±7.56
E-dimethylphenanthrene	4.09±0.03	0.24±0.35	4.07±0.00	3.67±3.79	6.35±0.36	16.85±7.92	53.50±53.54
C-dimethylphenanthrene	12.00±0.45	2.73±0.40	14.48±0.00	4.91±1.34	7.11±1.44	6.63±0.69	26.93±23.11
Fluoranthene	35.81±13.99	6.71±1.18	34.06±0.00	9.59±0.95	12.18±1.43	36.68±7.75	75.49±11.86
Pyrene	14.83±5.16	3.98±0.78	38.43±0.00	7.13±0.97	11.67±5.74	15.67±2.62	40.04±16.66

9-Anthraaldehyde	0.25±0.36	0.25±0.36	2.03±0.00	0.74±0.34	0.76±0.36	1.30±1.06	2.06±0.65
Retene	0.00±0.00	0.00±0.00	0.26±0.00	0.00±0.00	0.00±0.00	1.10±1.55	1.31±0.42
benzo(a)fluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.31±0.42
benzo(b)fluorene	0.51±0.00	0.00±0.00	0.26±0.00	0.00±0.00	1.02±0.72	0.51±0.72	0.53±0.76
5-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
B-MePy/MeFl	1.03±1.45	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.36	0.00±0.00	2.36±1.20
1-MeFl+C-MeFl/Py	0.00±0.00	0.00±0.00	0.00±0.00	0.24±0.35	2.79±3.95	0.00±0.00	1.01±1.43
1+3-methylfluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.24±0.35	0.25±0.36	0.55±0.77	0.00±0.00
4-methylpyrene	1.54±1.46	0.00±0.00	2.03±0.00	0.25±0.35	0.25±0.36	0.53±0.03	2.11±1.55
C-MePy/MeFl	0.77±0.37	0.00±0.00	0.51±0.00	0.00±0.00	1.27±1.79	0.51±0.72	0.53±0.76
D-MePy/MeFl	1.28±0.37	0.00±0.00	1.27±0.00	0.25±0.35	8.88±12.56	0.77±1.09	0.00±0.00
1-methylpyrene	0.77±0.37	0.00±0.00	1.27±0.00	0.25±0.35	1.01±1.44	0.53±0.03	1.84±1.18
Benzonaphthothiophene	2.03±2.87	0.73±1.04	3.80±0.00	0.99±1.40	2.79±3.23	0.82±1.16	0.00±0.00
benzo(c)phenanthrene	0.77±0.37	0.00±0.00	0.00±0.00	0.00±0.00	0.51±0.72	1.10±1.55	0.00±0.00
Benzo(ghi)fluoranthene	3.85±5.45	0.75±0.36	0.74±0.00	0.74±1.05	2.28±1.08	4.65±6.58	1.77±2.50
9-phenylanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Cyclopenta(c,d)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.36	0.00±0.00	0.00±0.00
Benz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzanthrone	0.25±0.36	0.00±0.00	0.00±0.00	0.24±0.35	0.76±1.08	0.55±0.77	0.50±0.71
Benz(a)anthracene-7,12-dione	0.77±1.09	0.00±0.00	0.00±0.00	0.24±0.35	0.00±0.00	0.00±0.00	0.00±0.00
3-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.24±0.35	0.25±0.36	0.00±0.00	0.00±0.00
7-methylbenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7,12-dimethylbenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.36	0.00±0.00	0.00±0.00
Benzo(b)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(j)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(a)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
BeP	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

BaP	0.25±0.36	0.00±0.00	0.00±0.00	0.24±0.35	0.51±0.00	0.00±0.00	0.00±0.00
Perylene	0.00±0.00	0.00±0.00	0.25±0.00	0.74±0.34	0.00±0.00	0.27±0.39	0.00±0.00
3-methylcholanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-methylbenzo(a)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.24±0.35	0.00±0.00	0.00±0.00	0.25±0.36
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Indeno[123-cd]fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Indeno[123-cd]pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah+ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.24±0.35	0.25±0.36	0.00±0.00	0.00±0.00
Dibenzo(ah)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,j)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(b)chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Picene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.36	0.00±0.00
Benzo(ghi)perylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Anthanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Triphenylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,l)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Coronene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,e)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,i)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,h)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(b,k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D6: Gas-phase PAH emission for Vehicle #6

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	208.81±79.54	146.94±28.88	507.56±43.64	215.29±10.88	824.16±702.48	1622.44±1986.07	440.10±0.00
quinoline	4.47±3.47	2.76±1.75	6.04±3.54	4.27±1.00	1.75±1.05	2.07±0.74	1.48±2.10
2-methylnaphthalene	80.90±8.67	75.84±2.69	143.17±2.70	106.76±4.54	348.19±62.84	123.22±57.16	517.86±398.46
1-methylnaphthalene	39.45±4.35	38.55±0.82	78.39±0.66	53.62±1.21	154.66±36.35	74.16±43.78	249.37±202.48
Biphenyl	30.65±11.20	26.71±1.74	54.70±4.14	25.91±2.08	166.69±34.84	93.10±85.11	317.57±299.63

2-methylbiphenyl	149.00±91.40	164.26±45.07	217.45±36.58	74.69±8.43	127.67±86.51	13225.80±18617.55	19446.11±27030.14
2,6+2,7-dimethylnaphthalene	41.13±13.16	32.75±1.10	66.55±4.54	41.54±1.73	268.61±42.91	57.31±12.68	307.68±224.16
1,3+1,6+1,7dimethylnaphth	67.32±20.19	56.19±1.74	111.92±5.43	66.73±3.55	410.68±97.78	93.46±23.08	451.68±316.05
1,4+1,5+2,3-dimethylnaphth	21.19±7.10	16.88±0.15	36.30±2.99	19.64±1.02	136.91±29.05	32.28±10.01	149.05±106.01
Acenaphthylene	1.25±0.37	1.51±0.69	8.06±0.68	2.26±1.03	13.25±8.05	3.35±1.81	12.59±11.52
1,2-dimethylnaphthalene	7.98±2.71	7.30±0.27	15.63±2.91	6.80±0.46	57.04±17.98	10.84±2.97	51.40±32.18
1,8-dimethylnaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Acenaphthene	11.70±6.54	11.08±0.13	22.69±2.94	9.82±0.51	79.58±19.22	86.96±106.98	272.44±323.12
3-methylbiphenyl	118.39±74.55	101.84±11.91	182.75±3.21	67.19±1.43	571.73±297.04	4038.13±5593.67	12214.09±16818.59
4-methylbiphenyl	44.78±26.18	44.40±11.22	75.61±6.12	27.68±0.27	256.58±109.25	1372.18±1896.19	5091.85±7032.61
1+2ethylnaphthalene	22.68±8.49	19.15±0.94	40.83±0.55	21.13±1.09	99.10±24.03	254.18±324.55	426.59±504.80
1-ethyl-2-methylnaphthalene	6.72±3.08	5.54±0.07	14.62±1.48	6.29±0.26	51.04±14.48	9.81±0.05	54.02±37.28
2,3,5+I-trimethylnaphthalene	23.89±13.07	18.63±1.20	43.86±2.31	21.44±5.68	229.37±86.43	33.31±7.82	191.37±124.64
B-trimethylnaphthalene	28.38±13.71	21.91±1.52	48.91±5.18	25.72±6.10	245.60±99.42	32.25±0.21	203.04±126.47
A-trimethylnaphthalene	35.11±16.08	27.71±0.38	57.23±6.28	33.28±7.65	274.72±83.60	43.88±3.86	282.35±207.91
C-trimethylnaphthalene	28.39±13.00	22.91±1.51	48.66±6.25	26.23±6.82	254.12±98.64	34.84±2.72	213.54±134.35
2-ethyl-1-methylnaphthalene	0.00±0.00	0.50±0.71	1.26±0.36	0.76±0.37	6.75±4.55	1.03±0.00	7.69±5.99
E-trimethylnaphthalene	17.43±8.93	13.60±0.55	30.50±2.61	15.89±4.17	154.54±69.65	23.49±4.86	136.21±80.17
2,4,5-trimethylnaphthalene	3.00±0.05	3.78±0.31	8.57±0.68	3.78±0.42	48.76±21.94	5.68±0.76	87.54±88.87
F-trimethylnaphthalene	16.18±8.59	12.34±0.92	28.74±0.83	14.63±4.50	160.84±57.92	21.17±3.75	128.31±76.68
Fluorene	32.36±17.18	26.44±2.18	63.77±1.32	24.18±1.81	329.65±65.82	33.81±1.26	255.06±150.44
1,4,5-trimethylnaphthalene	4.76±1.13	6.78±3.13	9.82±3.17	6.30±1.17	54.57±9.50	18.61±13.23	30.75±7.85
J-trimethylnaphthalene	11.70±5.83	9.06±1.32	19.16±1.50	10.09±3.01	120.57±42.99	15.23±2.63	56.03±7.29
A-Methylfluorene	10.98±1.95	12.83±3.05	14.37±1.84	11.86±3.39	113.39±41.97	12.64±0.30	109.17±96.41
B-Methylfluorene	2.49±0.67	2.02±0.02	2.27±1.77	2.02±0.74	21.32±7.60	2.84±0.38	15.78±5.55
1-Methylfluorene	8.72±3.76	8.07±0.81	11.35±1.83	9.33±2.64	23.20±23.56	12.39±3.71	59.86±38.55
9-fluorenone	9.96±4.80	11.99±16.24	7.84±11.08	14.37±3.43	86.76±86.75	169.80±219.77	98.41±88.17
Dibenzothiophene	1.25±0.33	0.75±0.35	2.77±0.35	0.75±1.06	18.84±13.96	1.81±1.10	18.35±7.79
Phenanthrene	64.06±22.00	67.72±6.67	90.51±12.12	60.74±10.57	774.82±205.09	113.67±54.56	547.99±385.19
Anthracene	3.49±1.36	2.52±0.03	4.54±0.02	2.52±0.04	20.06±6.53	2.32±1.08	12.04±8.64

Xanthone	2.24±1.03	1.76±0.34	2.52±0.72	2.53±1.46	15.31±8.27	3.62±1.48	21.66±23.64
1,4-Naphthoquinone	0.25±0.36	0.75±1.06	5.81±8.22	0.00±0.00	3.25±1.75	2.83±4.00	23.53±15.12
Acenaphthenequinone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-methylphenanthrene	11.22±3.01	15.84±4.44	12.86±3.26	17.22±13.80	96.85±41.13	25.59±16.55	65.79±30.17
2-methylphenanthrene	6.22±3.09	6.05±0.07	10.08±0.75	6.05±1.52	89.27±23.36	10.33±4.43	58.81±36.37
Perinaphthenone	0.50±0.01	0.76±0.37	0.00±0.00	1.76±0.38	7.97±11.27	5.70±8.06	17.30±20.27
2-methylanthracene	10.73±2.31	13.11±1.58	15.13±2.91	4.79±1.14	44.99±38.25	7.48±3.25	21.46±2.48
4,5-methylenephenanthrene	2.00±0.03	3.28±0.40	1.51±0.01	1.77±1.10	13.02±2.02	4.40±4.77	14.27±6.21
9-methylphenanthrene	3.74±1.71	4.03±0.66	5.29±0.38	3.03±0.76	48.64±11.71	6.46±1.86	32.47±20.08
1-methylphenanthrene	2.24±1.03	2.51±0.68	3.53±1.44	2.52±0.75	34.62±13.02	1.54±1.45	22.03±15.78
Anthrone	1.99±0.68	1.01±0.72	5.05±2.87	2.01±0.03	2.77±3.92	3.62±5.13	32.00±36.88
9-methylanthracene	0.50±0.01	0.25±0.36	0.50±0.00	0.25±0.36	1.25±0.36	1.55±2.20	2.84±3.32
Anthraquinone	262.91±361.09	0.25±0.36	394.48±387.96	11.32±0.89	133.69±19.51	18.88±19.43	237.60±32.85
A-dimethylphenanthrene	1.25±0.33	1.26±0.37	2.27±0.37	0.76±0.37	12.27±0.26	1.55±0.74	8.42±4.22
B-dimethylphenanthrene	0.99±0.69	1.01±0.72	1.26±0.36	0.76±0.37	12.54±2.93	1.29±1.10	18.27±18.16
1,7-dimethylphenanthrene	0.99±0.69	1.01±0.01	1.77±0.36	1.26±0.38	16.29±3.31	1.81±1.10	23.72±25.86
3,6-dimethylphenanthrene	1.00±0.02	1.01±0.01	1.26±0.36	0.76±0.37	13.27±0.96	1.29±0.37	35.89±42.38
D-dimethylphenanthrene	1.25±0.33	1.52±1.44	1.26±0.36	0.76±0.37	11.03±2.92	1.03±0.73	7.66±3.84
E-dimethylphenanthrene	9.48±1.98	11.60±2.28	15.89±5.41	4.03±0.78	38.51±48.12	6.19±2.89	25.02±1.64
C-dimethylphenanthrene	2.24±1.03	2.27±0.38	4.54±1.44	2.52±0.75	31.09±7.33	3.62±1.48	25.61±18.05
Fluoranthene	3.98±2.77	3.54±1.47	9.33±1.82	3.78±0.42	71.13±3.70	7.75±5.15	41.72±28.27
Pyrene	3.48±2.77	3.02±0.04	8.32±3.24	3.28±1.12	42.03±12.43	3.88±2.57	21.45±11.47
9-Anthraaldehyde	0.25±0.35	0.25±0.36	0.50±0.71	0.25±0.35	2.01±1.43	0.52±0.73	2.26±1.00
Retene	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	1.00±0.01	0.00±0.00	0.51±0.02
benzo(a)fluorene	0.00±0.00	0.00±0.00	0.75±1.07	0.00±0.00	0.50±0.00	0.00±0.00	1.02±0.75
benzo(b)fluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.04±1.47
5-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
B-MePy/MeFl	0.25±0.35	0.00±0.00	1.26±1.78	0.00±0.00	0.00±0.00	0.00±0.00	1.30±1.83
1-MeFl+C-MeFl/Py	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	5.69±7.35
1+3-methylfluoranthene	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	9.33±13.20

4-methylpyrene	0.00±0.00	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	4.15±5.87
C-MePy/MeFl	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.81±2.57
D-MePy/MeFl	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	5.44±7.70
1-methylpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.30±1.83
Benzonaphthothiophene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37	6.74±9.53
benzo(c)phenanthrene	0.25±0.35	0.00±0.00	0.25±0.36	0.00±0.00	0.00±0.00	0.00±0.00	3.09±2.97
Benzo(ghi)fluoranthene	1.24±1.04	0.75±1.06	0.76±1.07	0.76±0.37	0.00±0.00	0.00±0.00	7.00±9.90
9-phenylanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.35	0.00±0.00	0.26±0.37
6-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Cyclopenta(c,d)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.35	0.00±0.00	1.04±1.47
Benz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.78±1.10
Chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzanthrone	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.52±0.73	4.41±6.23
Benz(a)anthracene-7,12-dione	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	2.07±2.93
3-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.52±0.73
7-methylbenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37
7,12-dimethylbenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.30±1.83
Benzo(b)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(j)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(a)fluoranthene	0.00±0.00	0.00±0.00	0.25±0.36	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.35
BeP	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
BaP	0.00±0.00	0.76±0.37	0.00±0.00	0.00±0.00	0.25±0.35	0.00±0.00	0.00±0.00
Perylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.25±0.36	0.00±0.00	0.00±0.00
3-methylcholanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-methylbenzo(a)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37	0.26±0.37
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37
Indeno[123-cd]fluoranthene	0.00±0.00	0.00±0.00	0.75±1.07	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37
Indeno[123-cd]pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Dibenzo(ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah+ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,j)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(b)chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Picene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(ghi)perylene	0.00±0.00	0.25±0.35	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Anthanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Triphenylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,l)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Coronene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,e)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,i)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,h)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(b,k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D7: Gas-phase PAH emission for Vehicle #7

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	367.21±177.17	473.93±135.27	2319.15±2159.42	1979.09±1859.93	515.67±62.01	1019.03±162.07	252.78±101.81
quinoline	50.11±37.65	16.76±0.90	97.93±70.51	30.08±3.04	42.23±21.26	58.55±2.27	7.22±8.50
2-methylnaphthalene	265.53±205.53	309.15±82.02	946.77±494.35	413.45±56.00	411.78±24.43	535.39±28.07	114.49±86.24
1-methylnaphthalene	164.23±116.20	164.82±47.17	574.24±350.95	254.39±34.48	240.61±12.70	330.20±13.68	65.46±51.53
Biphenyl	29.48±16.67	33.92±6.32	161.99±134.91	115.80±103.04	57.65±21.33	108.00±51.43	29.51±10.95
2,6+2,7-dimethylnaphthalene	51.48±31.82	52.28±15.62	229.57±177.28	92.69±30.86	111.49±18.65	186.65±90.36	42.34±14.13
1,3+1,6+1,7dimethylnaphth	107.24±67.10	95.78±30.66	403.31±304.31	152.28±19.59	189.66±13.55	296.98±133.82	74.29±25.97
1,4+1,5+2,3-dimethylnaphth	31.77±19.48	27.89±7.43	133.43±105.08	47.48±8.96	59.04±6.40	93.34±42.82	22.62±7.62
Acenaphthylene	2.29±1.95	1.31±1.86	3.11±0.59	1.99±0.16	1.68±1.08	7.75±1.60	2.75±0.90
1,2-dimethylnaphthalene	10.69±6.06	10.45±4.25	10.43±11.43	7.70±7.79	22.33±6.02	34.92±19.95	8.86±1.41
1,8-dimethylnaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Acenaphthene	5.65±1.52	7.55±2.78	85.42±108.98	76.83±99.31	15.90±14.25	32.33±22.34	10.99±1.87
1+2ethylnaphthalene	31.93±20.56	33.21±10.57	373.48±418.80	312.29±370.30	61.48±5.96	103.41±33.25	22.33±9.35
1-ethyl-2-methylnaphthalene	7.48±2.39	5.76±1.13	17.71±11.11	11.50±0.55	14.07±6.90	25.25±13.20	8.55±1.40
2,3,5+I-trimethylnaphthalene	12.06±2.39	16.09±7.41	30.10±19.34	23.88±9.14	34.24±28.93	82.76±60.76	21.23±3.94
B-trimethylnaphthalene	16.49±3.91	21.02±6.93	46.04±29.21	28.72±4.52	44.95±28.92	95.79±64.03	27.64±4.45
A-trimethylnaphthalene	23.83±9.97	24.72±8.65	72.44±48.39	38.87±7.41	56.88±32.79	119.51±78.97	33.73±3.24
C-trimethylnaphthalene	16.34±4.56	19.75±6.88	42.80±25.90	28.56±3.86	43.42±30.22	91.69±64.29	27.33±3.59
2-ethyl-1-methylnaphthalene	0.46±0.22	0.32±0.01	1.47±1.24	0.78±0.67	1.38±0.65	2.58±0.18	0.76±0.21
E-trimethylnaphthalene	10.54±3.69	11.72±4.30	29.36±19.98	19.08±5.75	25.99±20.73	62.23±43.85	17.56±2.60
2,4,5-trimethylnaphthalene	2.90±1.08	3.04±0.80	6.79±4.53	4.61±1.00	6.73±5.61	17.67±13.30	4.43±1.14
F-trimethylnaphthalene	7.94±2.17	10.27±3.57	20.35±15.27	14.49±6.05	24.00±19.22	57.68±43.48	15.42±2.14
Fluorene	15.27±4.34	21.06±8.73	33.07±17.63	21.66±3.88	53.49±56.16	111.55±91.08	28.99±1.23
1,4,5-trimethylnaphthalene	1.22±0.00	2.25±0.99	16.05±16.78	13.82±12.32	7.80±7.56	18.43±12.21	5.19±0.93
J-trimethylnaphthalene	5.35±1.09	6.25±1.83	12.83±8.86	9.54±2.44	16.66±13.60	41.51±33.60	10.98±0.29
A-Methylfluorene	6.11±0.44	18.19±15.05	31.34±35.46	5.52±0.16	17.73±16.85	31.01±14.85	11.29±0.29
B-Methylfluorene	1.37±0.65	6.57±1.84	9.03±0.11	0.76±0.63	3.21±2.37	7.10±4.85	2.29±0.25
1-Methylfluorene	6.11±3.90	59.41±74.28	122.67±96.20	6.44±0.62	12.23±9.93	22.36±14.74	6.71±0.52

9-fluorenone	10.84±2.82	211.01±273.83	205.65±269.29	175.52±247.79	18.80±13.60	8.87±11.70	10.23±1.64
Dibenzothiophene	0.31±0.43	0.80±0.26	4.28±2.67	0.78±0.67	1.22±0.86	2.41±2.12	0.15±0.22
Phenanthrene	38.18±9.99	57.77±26.88	96.15±70.95	64.27±36.54	108.06±110.80	199.28±134.18	55.85±4.17
Anthracene	1.83±0.87	4.49±1.08	4.43±2.46	1.23±0.47	3.82±4.54	10.71±9.95	1.82±0.84
Xanthone	1.83±0.87	1.77±0.75	3.84±1.63	2.47±1.37	2.75±2.16	5.15±1.65	1.98±0.24
1,4-Naphthoquinone	3.21±2.81	2.90±1.47	22.84±20.47	6.11±1.12	9.02±0.23	0.00±0.00	6.62±9.36
Acenaphthenequinone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-methylphenanthrene	8.55±0.44	9.06±6.67	20.37±11.91	20.66±8.83	21.39±25.93	18.02±5.57	17.15±11.00
2-methylphenanthrene	5.19±1.74	5.80±2.94	8.56±4.51	6.18±3.21	11.46±11.88	17.53±10.51	5.95±0.72
Perinaphthenone	0.15±0.22	0.96±0.04	4.56±5.18	3.58±3.79	0.00±0.00	1.07±1.52	0.15±0.21
2-methylanthracene	5.04±1.52	7.30±6.38	6.21±1.19	3.02±2.95	14.21±16.20	34.92±3.44	3.83±1.99
4,5-methylenephenanthrene	1.38±1.08	2.73±0.79	3.68±4.36	3.75±5.31	5.20±5.62	6.18±5.72	2.59±0.25
9-methylphenanthrene	3.67±2.16	3.86±1.51	5.46±2.66	3.86±2.06	6.72±6.91	9.83±5.24	3.51±0.69
1-methylphenanthrene	2.29±0.65	2.25±0.99	2.36±2.07	1.99±0.16	6.11±6.91	8.30±6.55	2.29±0.19
Anthrone	0.46±0.65	0.80±0.26	1.19±0.43	1.24±0.90	1.83±2.16	3.47±3.18	0.76±0.64
9-methylanthracene	0.31±0.43	0.16±0.22	1.92±1.44	1.72±2.43	0.61±0.43	0.45±0.21	0.31±0.00
Anthraquinone	15.59±16.87	39.37±0.00	51.35±18.60	61.81±4.18	53.97±28.25	139.60±0.00	14.00±19.38
A-dimethylphenanthrene	1.68±1.08	1.29±0.50	1.63±0.19	1.08±0.25	2.14±2.16	3.64±0.38	1.53±0.45
B-dimethylphenanthrene	1.68±1.08	0.97±0.49	1.04±0.64	1.39±0.69	1.83±1.73	1.66±0.62	0.92±0.01
1,7-dimethylphenanthrene	1.99±1.51	1.13±0.72	1.48±0.02	1.23±0.47	2.29±1.94	4.39±1.88	1.37±0.20
3,6-dimethylphenanthrene	1.22±0.87	2.52±1.70	6.97±1.13	1.08±0.68	1.68±1.94	1.97±1.05	0.61±0.01
D-dimethylphenanthrene	1.99±1.95	1.13±0.72	1.03±0.62	0.77±0.24	1.38±1.51	26.78±35.71	2.77±3.06
E-dimethylphenanthrene	2.75±0.44	4.69±3.57	5.18±0.15	3.50±1.85	20.17±27.22	9.42±2.69	0.76±0.21
C-dimethylphenanthrene	3.97±3.03	2.26±1.44	3.41±0.25	2.62±1.16	4.74±4.54	5.27±5.73	2.29±0.25
Fluoranthene	3.82±1.09	9.04±2.57	17.61±1.68	5.41±3.41	7.95±7.78	16.47±10.31	3.97±0.05
Pyrene	4.43±2.81	5.47±2.47	5.18±0.99	2.77±0.95	6.42±6.48	11.36±2.22	2.90±0.25
9-Anthraaldehyde	0.61±0.43	0.32±0.01	0.45±0.21	0.00±0.00	0.61±0.43	2.76±3.90	0.15±0.22
Retene	0.15±0.22	0.00±0.00	0.15±0.21	0.00±0.00	0.15±0.22	0.15±0.21	0.00±0.00
benzo(a)fluorene	0.00±0.00	0.00±0.00	0.15±0.21	0.00±0.00	0.00±0.00	0.15±0.21	0.00±0.00
benzo(b)fluorene	0.15±0.22	0.00±0.00	0.15±0.21	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

5-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
B-MePy/MeFl	0.15±0.22	0.00±0.00	0.00±0.00	0.31±0.44	0.00±0.00	0.30±0.43	0.00±0.00
1-MeFl+C-MeFl/Py	0.00±0.00	0.00±0.00	0.44±0.62	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1+3-methylfluoranthene	0.00±0.00	0.00±0.00	0.29±0.42	0.16±0.22	0.00±0.00	0.00±0.00	0.15±0.21
4-methylpyrene	1.38±1.51	0.00±0.00	0.45±0.63	0.47±0.66	0.31±0.43	0.30±0.43	0.15±0.22
C-MePy/MeFl	0.15±0.22	0.00±0.00	0.00±0.00	0.16±0.22	0.15±0.22	0.00±0.00	0.00±0.00
D-MePy/MeFl	1.22±1.30	0.00±0.00	0.30±0.42	0.16±0.22	0.00±0.00	0.15±0.22	0.00±0.00
1-methylpyrene	1.22±1.30	0.00±0.00	0.30±0.42	0.31±0.44	0.31±0.43	0.45±0.64	0.15±0.22
Benzonaphthothiophene	0.00±0.00	0.00±0.00	0.00±0.00	0.31±0.44	0.00±0.00	0.00±0.00	0.00±0.00
benzo(c)phenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.15±0.22	0.15±0.21	0.00±0.00
Benzo(ghi)fluoranthene	1.07±0.65	0.33±0.46	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.46±0.21
9-phenylanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Cyclopenta(c,d)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzanthrone	0.00±0.00	0.16±0.23	0.59±0.83	0.16±0.22	0.00±0.00	0.00±0.00	0.00±0.00
Benz(a)anthracene-7,12-dione	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.30±0.43
3-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.15±0.22	0.15±0.21	0.00±0.00
7-methylbenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7,12-dimethylbenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(b)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(j)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(a)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.15±0.21	0.00±0.00
BeP	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
BaP	0.00±0.00	0.16±0.23	0.15±0.21	0.15±0.21	0.15±0.22	0.00±0.00	0.31±0.00
Perylene	0.00±0.00	0.16±0.23	0.00±0.00	0.15±0.21	0.15±0.22	0.31±0.43	0.15±0.22
3-methylcholanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-methylbenzo(a)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Indeno[123-cd]fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Indeno[123-cd]pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah+ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,j)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(b)chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Picene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(ghi)perylene	0.00±0.00	0.00±0.00	0.15±0.21	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Anthanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Triphenylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,l)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Coronene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,e)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,i)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,h)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(b,k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D8: Gas-phase PAH emission for Vehicle #8

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	1122.68±97.27	1403.07±242.14	791.07±97.04	1109.76±53.24	164.54±59.91	1678.90±435.37	136.40±28.55
quinoline	40.43±17.13	41.74±13.39	41.70±6.83	45.37±3.15	1.26±1.19	67.91±21.95	0.41±0.00
2-methylnaphthalene	644.80±102.11	702.50±178.35	457.78±3.82	620.58±32.34	67.57±28.73	745.00±311.19	45.81±10.79
1-methylnaphthalene	353.38±35.64	378.15±97.45	244.97±14.06	326.99±9.57	34.21±13.47	394.35±160.70	22.18±4.37
Biphenyl	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	19.03±2.83	0.00±0.00	17.41±5.25
2,6+2,7-dimethylnaphthalene	185.48±8.95	150.11±29.05	113.57±16.34	155.67±11.99	28.76±3.34	141.51±17.18	22.60±3.78
1,3+1,6+1,7dimethylnaphth	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	48.83±8.25	0.00±0.00	38.14±5.81
1,4+1,5+2,3-dimethylnaphth	98.41±6.32	80.42±17.22	59.29±12.05	88.29±1.61	14.38±0.47	74.00±11.44	12.02±2.33
Acenaphthylene	9.22±6.85	39.51±21.73	9.73±15.83	24.69±4.11	0.63±0.29	31.01±31.42	1.04±0.29

1,2-dimethylnaphthalene	35.47±33.84	37.60±38.38	28.19±12.10	14.79±1.65	5.92±1.74	65.17±1.87	4.56±0.58
1,8-dimethylnaphthalene	38.64±15.94	48.12±8.60	28.10±6.09	55.14±3.45	0.00±0.00	50.58±3.01	0.00±0.00
Acenaphthene	74.09±3.83	55.65±16.33	63.79±14.80	51.61±0.28	10.58±1.29	74.56±17.04	12.02±5.26
1+2ethylnaphthalene	55.23±8.98	48.62±8.25	36.31±7.57	47.00±0.20	9.90±9.79	50.05±10.66	2.07±1.76
1-ethyl-2-methylnaphthalene	264.94±57.38	257.21±14.80	176.97±22.09	292.63±26.03	4.02±0.26	277.20±3.30	3.73±0.01
2,3,5+I-trimethylnaphthalene	107.22±24.64	56.09±7.68	55.02±16.88	85.57±18.52	19.06±3.76	44.56±19.11	17.20±5.55
B-trimethylnaphthalene	121.02±34.04	81.19±10.99	60.58±11.46	106.71±15.10	20.94±0.72	59.20±6.34	17.21±2.03
A-trimethylnaphthalene	32.35±10.90	31.48±4.27	19.20±4.96	31.09±1.13	24.54±0.98	29.46±0.41	21.35±3.78
C-trimethylnaphthalene	168.34±33.40	130.71±20.20	92.23±12.90	133.98±11.02	21.79±0.49	102.77±9.01	18.03±3.20
2-ethyl-1-methylnaphthalene	7.89±2.10	4.41±3.00	1.12±0.92	5.12±2.38	0.85±0.01	0.97±0.85	0.62±0.29
E-trimethylnaphthalene	61.96±22.61	56.96±16.45	37.94±17.20	59.75±0.49	13.54±0.72	44.08±14.29	10.99±2.62
2,4,5-trimethylnaphthalene	35.89±8.67	26.62±4.93	24.08±4.97	27.05±0.45	3.17±0.27	21.76±3.16	3.52±1.46
F-trimethylnaphthalene	178.15±47.08	135.89±37.58	89.92±8.59	146.22±10.47	12.49±2.20	99.81±12.94	10.99±2.62
Fluorene	153.49±28.68	122.52±19.82	118.62±7.46	122.42±2.01	15.24±0.73	136.62±15.28	15.55±4.38
1,4,5-trimethylnaphthalene	4.09±2.25	1.63±2.19	1.43±1.48	0.59±0.83	2.32±1.48	8.62±7.54	1.24±0.58
J-trimethylnaphthalene	24.39±8.25	17.43±3.47	13.90±4.80	16.78±0.45	10.79±0.99	11.14±8.84	9.54±2.33
A-Methylfluorene	46.89±15.41	40.73±9.44	32.79±14.85	35.97±5.00	6.99±0.96	42.92±1.50	6.84±4.98
B-Methylfluorene	33.16±4.76	22.85±14.49	19.28±5.34	23.52±1.26	7.64±6.65	16.76±3.68	9.13±8.81
1-Methylfluorene	66.60±20.69	66.71±21.92	57.33±2.84	37.44±10.49	4.44±0.26	70.23±5.47	4.15±0.58
9-fluorenone	101.07±32.16	82.26±12.97	64.96±10.36	89.47±5.23	5.53±7.23	266.15±168.91	1.24±0.00
Dibenzothiophene	18.80±6.12	16.57±2.23	14.26±2.65	10.65±0.19	0.21±0.30	19.00±0.60	0.21±0.29
Phenanthrene	348.84±112.52	220.16±18.46	176.90±15.44	243.12±22.72	38.73±3.63	526.04±266.20	42.29±8.15
Anthracene	10.28±1.96	7.83±3.89	5.80±5.22	7.68±1.70	0.63±0.29	25.63±11.87	0.42±0.59
Xanthone	5.18±1.10	7.86±0.97	4.84±2.03	6.29±0.64	1.27±0.01	16.61±9.21	1.24±0.00
1,4-Naphthoquinone	100.70±48.49	292.33±168.73	157.25±87.98	113.62±155.48	1.27±0.61	470.32±100.90	0.42±0.59
Acenaphthenequinone	26.97±2.98	21.83±1.04	16.43±1.91	17.98±3.15	0.00±0.00	17.83±2.68	0.00±0.00
3-methylphenanthrene	47.40±17.52	28.19±7.58	23.13±4.60	30.02±4.72	6.35±1.25	41.87±1.34	6.22±1.75
2-methylphenanthrene	48.97±17.50	31.94±3.63	22.85±4.31	30.59±0.24	3.39±1.23	37.28±4.21	4.15±1.17
Perinaphthenone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.43±0.60	0.00±0.00	0.41±0.00
2-methylanthracene	10.23±2.16	6.95±0.91	5.21±0.57	6.98±0.16	6.34±0.54	7.45±0.91	6.01±2.63

4,5-methylenephenanthrene	13.13±7.89	11.80±2.03	7.29±0.80	11.38±0.36	1.06±1.51	13.19±2.50	1.87±0.88
9-methylphenanthrene	26.39±9.71	17.19±1.74	12.04±2.04	15.74±0.29	2.54±0.62	18.49±3.36	2.69±0.88
1-methylphenanthrene	25.63±6.89	16.10±1.17	14.70±5.14	21.47±1.62	1.69±0.58	23.30±4.41	2.07±0.00
Anthrone	4.49±7.77	6.87±11.89	14.08±24.38	0.00±0.00	1.48±0.29	91.98±159.31	1.24±0.00
9-methylanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.21±0.30	0.00±0.00	0.21±0.29
Anthraquinone	5.90±3.71	12.56±6.83	5.42±1.18	9.93±3.55	5.95±5.44	9.56±8.29	10.15±7.32
A-dimethylphenanthrene	9.35±4.77	7.06±0.56	3.62±2.11	6.02±1.25	0.64±0.30	10.96±2.25	1.24±0.58
B-dimethylphenanthrene	4.96±1.50	1.14±0.99	2.58±2.15	2.63±0.90	0.64±0.30	2.84±0.74	1.04±0.88
1,7-dimethylphenanthrene	10.95±3.13	6.85±6.01	5.02±4.35	3.48±4.93	1.27±0.01	4.99±8.64	1.04±1.46
3,6-dimethylphenanthrene	5.46±1.12	2.13±0.95	3.06±1.68	2.53±1.23	1.06±0.91	4.25±0.99	1.87±0.30
D-dimethylphenanthrene	9.27±3.64	4.21±0.60	4.57±1.47	4.88±0.17	3.19±4.52	6.17±0.94	6.22±0.01
E-dimethylphenanthrene	0.93±1.60	0.68±0.79	0.94±0.82	1.88±0.30	2.77±3.91	1.65±0.14	3.11±0.88
C-dimethylphenanthrene	8.11±14.05	14.79±25.61	0.00±0.00	0.00±0.00	1.70±0.61	42.18±6.07	2.28±0.88
Fluoranthene	53.57±15.08	48.23±7.48	33.39±12.61	39.08±2.60	4.24±2.43	128.98±88.60	8.08±2.63
Pyrene	26.64±10.07	30.72±11.55	18.36±14.05	20.99±2.75	2.12±0.62	109.07±79.37	2.90±1.17
9-Anthraaldehyde	43.27±17.41	26.51±9.11	26.30±3.74	28.19±1.90	0.42±0.59	31.57±2.36	0.62±0.88
Retene	0.71±0.12	1.08±0.05	0.69±0.27	0.84±0.03	0.00±0.00	0.87±0.42	0.00±0.00
benzo(a)fluorene	0.82±1.43	0.52±0.90	0.66±1.13	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
benzo(b)fluorene	0.19±0.33	0.30±0.33	0.42±0.47	0.83±0.10	0.00±0.00	1.19±2.06	0.00±0.00
5-methylchrysene	1.45±2.51	0.33±0.58	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
B-MePy/MeFl	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-MeFl+C-MeFl/Py	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1+3-methylfluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.87±3.24	0.00±0.00
4-methylpyrene	2.02±2.97	1.63±1.33	2.45±3.42	1.71±0.62	0.21±0.30	3.56±2.47	0.21±0.29
C-MePy/MeFl	0.49±0.55	0.28±0.48	0.60±1.04	0.39±0.55	0.00±0.00	0.00±0.00	0.00±0.00
D-MePy/MeFl	2.23±3.18	0.28±0.32	2.68±3.62	0.98±0.10	0.21±0.30	2.59±0.81	0.00±0.00
1-methylpyrene	0.50±0.87	0.94±1.47	1.37±2.30	0.20±0.28	0.00±0.00	0.16±0.19	0.00±0.00
Benzonaphthothiophene	0.00±0.00	0.07±0.12	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
benzo(c)phenanthrene	0.20±0.34	0.25±0.44	0.27±0.47	0.00±0.00	0.21±0.30	0.38±0.66	0.21±0.29
Benzo(ghi)fluoranthene	1.57±1.27	1.22±1.43	1.20±1.52	0.35±0.50	1.28±1.81	2.46±2.04	0.62±0.29

9-phenylanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	1.38±1.49	0.00±0.00
6-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.26±0.37	0.00±0.00	0.00±0.00	0.00±0.00
Cyclopenta(c,d)pyrene	0.64±0.56	1.09±1.31	0.00±0.00	0.30±0.43	0.00±0.00	0.28±0.48	0.00±0.00
Benz(a)anthracene	0.07±0.12	0.72±1.25	0.00±0.00	0.11±0.15	0.00±0.00	0.00±0.00	0.00±0.00
Chrysene	0.23±0.39	0.29±0.51	0.28±0.25	1.51±0.36	0.00±0.00	0.00±0.00	0.00±0.00
Benzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benz(a)anthracene-7,12-dione	4.01±6.95	33.36±57.78	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-methylchrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-methylbenz(a)anthracene	0.00±0.00	0.27±0.46	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7,12-dimethylbenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.21±0.29
Benzo(b)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.23±0.32	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(j)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(a)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
BeP	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
BaP	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.42±0.00	0.00±0.00	0.21±0.29
Perylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.42±0.00	0.00±0.00	0.41±0.00
3-methylcholanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-methylbenzo(a)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.42±0.59	0.00±0.00	0.21±0.29
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Indeno[123-cd]fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.21±0.30	0.00±0.00	0.21±0.29
Indeno[123-cd]pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(ah+ac)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.21±0.29
Dibenzo(ah)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,j)anthracene	0.05±0.09	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(b)chrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Picene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Benzo(ghi)perylene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Anthanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.36±0.51	0.00±0.00	0.00±0.00	0.00±0.00
Triphenylene	0.03±0.05	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,l)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Coronene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,e)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,i)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(a,h)pyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Dibenzo(b,k)fluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D9: Particle-phase PAH emissions for Vehicle #1

Component (ng/mile)	Fed ULSD	CARB USLD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Naphthalene	0.41 ± 0.58	3.72 ± 5.26	0.00 ± 0.00	0.00 ± 0.00	71.45 ± 101.04	10.87 ± 15.37	5.39 ± 7.62
Quinoline	0.00 ± 0.00	7.69 ± 10.87	0.00 ± 0.00	1.75 ± 2.48	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
2-methylnaphthalene	16.49 ± 17.85	14.81 ± 20.94	0.00 ± 0.00	13.25 ± 12.18	57.14 ± 67.95	15.51 ± 21.93	20.29 ± 28.69
1-methylnaphthalene	7.03 ± 9.94	6.13 ± 5.72	4.69 ± 3.65	6.16 ± 6.98	31.27 ± 44.23	13.35 ± 18.88	11.45 ± 16.20
Biphenyl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.53 ± 0.75	1.39 ± 1.96	1.31 ± 1.85	0.00 ± 0.00
2-methylbiphenyl	11.87 ± 1.93	14.44 ± 10.12	11.54 ± 1.12	15.20 ± 3.24	7.73 ± 10.93	8.50 ± 4.63	7.39 ± 0.19
2,6+2,7-dimethylnaphthalene	2.61 ± 3.70	5.01 ± 2.81	3.61 ± 2.15	1.11 ± 1.19	4.64 ± 2.40	4.66 ± 6.59	1.76 ± 2.49
1,3+1,6+1,7dimethylnaphth	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1,4+1,5+2,3-dimethylnaphth	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	7.14 ± 10.09	34.77 ± 38.52	24.34 ± 1.92	0.00 ± 0.00
Acenaphthylene	1.39 ± 1.96	1.64 ± 2.32	1.98 ± 2.79	1.43 ± 2.02	1.55 ± 2.20	0.00 ± 0.00	0.00 ± 0.00
1,2-dimethylnaphthalene	7.01 ± 0.28	4.02 ± 0.36	0.80 ± 1.13	5.71 ± 5.55	0.00 ± 0.00	2.40 ± 2.33	6.99 ± 1.34
1,8-dimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthene	3.93 ± 0.22	1.90 ± 2.68	2.55 ± 3.61	3.79 ± 5.36	1.86 ± 2.64	4.93 ± 1.83	1.79 ± 2.53

3-methylbiphenyl	1.74 ± 2.46	4.78 ± 6.76	0.00 ± 0.00	14.77 ± 18.90	3.43 ± 4.85	5.37 ± 7.60	0.00 ± 0.00
4-methylbiphenyl	2.11 ± 2.94	4.07 ± 5.75	1.27 ± 1.80	13.10 ± 14.98	0.19 ± 0.26	7.29 ± 4.77	0.00 ± 0.00
1+2ethylnaphthalene	3.77 ± 5.34	79.64 ± 39.00	89.35 ± 8.53	32.94 ± 25.70	77.23 ± 40.08	60.44 ± 6.94	12.52 ± 17.70
1-ethyl-2-methylnaphthalene	20.53 ± 29.03	3.46 ± 0.20	1.60 ± 2.26	0.00 ± 0.00	13.47 ± 19.05	0.00 ± 0.00	1.32 ± 1.87
2,3,5+I-trimethylnaphthalene	2.40 ± 0.63	5.66 ± 0.37	3.93 ± 1.76	5.16 ± 1.73	12.22 ± 11.63	5.05 ± 0.33	3.08 ± 1.62
B-trimethylnaphthalene	14.39 ± 17.13	17.60 ± 23.07	19.30 ± 26.11	2.98 ± 0.02	7.19 ± 7.67	2.60 ± 0.76	27.24 ± 3.71
A-trimethylnaphthalene	0.00 ± 0.00	0.83 ± 1.18	0.00 ± 0.00	0.00 ± 0.00	10.53 ± 14.90	0.00 ± 0.00	1.35 ± 1.91
C-trimethylnaphthalene	0.00 ± 0.00	0.11 ± 0.16	0.38 ± 0.53	0.00 ± 0.00	5.03 ± 7.12	0.00 ± 0.00	0.00 ± 0.00
2-ethyl-1-methylnaphthalene	0.00 ± 0.00	0.85 ± 0.50	0.77 ± 1.10	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.70	0.00 ± 0.00
E-trimethylnaphthalene	0.76 ± 0.67	2.94 ± 4.15	0.00 ± 0.00	0.59 ± 0.84	4.98 ± 6.95	0.00 ± 0.00	0.00 ± 0.00
2,4,5-trimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
F-trimethylnaphthalene	1.66 ± 2.09	1.24 ± 1.75	0.00 ± 0.00	0.41 ± 0.58	2.15 ± 2.95	0.90 ± 1.27	0.00 ± 0.00
Fluorene	1.63 ± 1.32	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1,4,5-trimethylnaphthalene	0.00 ± 0.00	2.66 ± 3.76	16.94 ± 23.95	4.68 ± 6.62	0.00 ± 0.00	3.08 ± 1.91	0.00 ± 0.00
J-trimethylnaphthalene	2.80 ± 3.95	3.07 ± 1.46	3.26 ± 0.99	4.33 ± 1.95	1.77 ± 2.51	2.94 ± 4.15	2.79 ± 0.18
A-Methylfluorene	2.67 ± 1.91	3.26 ± 4.39	3.57 ± 0.60	1.93 ± 1.00	8.37 ± 10.04	0.00 ± 0.00	6.96 ± 8.22
B-Methylfluorene	0.00 ± 0.00	2.23 ± 3.15	3.19 ± 0.28	0.00 ± 0.00	0.00 ± 0.00	2.38 ± 3.36	2.70 ± 3.83
1-Methylfluorene	3.74 ± 0.59	4.78 ± 0.71	5.40 ± 0.96	1.93 ± 2.73	10.75 ± 10.30	7.22 ± 2.89	5.16 ± 0.20
9-fluorenone	6.85 ± 1.61	6.54 ± 1.23	4.59 ± 3.48	3.46 ± 4.90	0.00 ± 0.00	2.90 ± 4.10	5.72 ± 0.64
Dibenzothiophene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.11 ± 1.57	0.00 ± 0.00	0.82 ± 1.16	0.00 ± 0.00
Phenanthrene	0.00 ± 0.00	5.66 ± 5.23	9.89 ± 2.07	14.31 ± 20.23	7.13 ± 5.95	12.09 ± 13.16	0.00 ± 0.00
Anthracene	1.24 ± 1.75	1.40 ± 1.98	0.39 ± 0.55	0.81 ± 1.15	2.55 ± 3.61	0.64 ± 0.90	1.20 ± 1.70

Xanthone	14.58 ± 4.72	25.06 ± 10.55	18.25 ± 0.11	14.75 ± 1.01	18.48 ± 26.14	4.72 ± 1.37	6.45 ± 5.17
1,4-Naphthoquinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthenequinone	5.39 ± 7.62	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	3.41 ± 4.83	1.78 ± 2.52
3-methylphenanthrene	0.62 ± 0.88	4.31 ± 0.64	7.90 ± 1.29	1.44 ± 2.04	0.94 ± 1.33	3.10 ± 0.83	2.97 ± 4.19
2-methylphenanthrene	0.00 ± 0.00	0.49 ± 0.70	4.26 ± 2.26	1.39 ± 1.96	8.00 ± 11.32	2.90 ± 0.16	5.67 ± 8.02
Perinaphthenone	23.63 ± 1.02	24.81 ± 9.21	32.79 ± 25.25	10.46 ± 14.79	7.56 ± 10.70	11.18 ± 0.27	4.87 ± 6.89
2-methylanthracene	0.98 ± 1.39	0.43 ± 0.61	0.00 ± 0.00	1.10 ± 1.55	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
4,5-methylenephenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.31 ± 0.44	0.00 ± 0.00	0.24 ± 0.34	0.00 ± 0.00
9-methylphenanthrene	2.30 ± 3.25	2.95 ± 4.17	4.58 ± 0.94	6.38 ± 3.30	0.00 ± 0.00	3.15 ± 0.81	1.86 ± 2.63
1-methylphenanthrene	6.62 ± 0.82	7.07 ± 0.35	6.80 ± 2.63	8.59 ± 2.46	0.00 ± 0.00	7.08 ± 0.96	1.87 ± 2.64
Anthrone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
9-methylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Anthraquinone	10.55 ± 0.74	10.64 ± 4.56	17.36 ± 3.85	6.10 ± 0.82	2.18 ± 3.08	3.83 ± 5.42	9.13 ± 2.62
A-dimethylphenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-dimethylphenanthrene	3.36 ± 4.76	6.39 ± 0.29	6.60 ± 1.92	3.16 ± 4.46	2.12 ± 3.00	3.76 ± 0.62	5.65 ± 1.21
1,7-dimethylphenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.96 ± 1.35	1.56 ± 2.20	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3,6-dimethylphenanthrene	9.93 ± 0.26	3.18 ± 4.49	0.27 ± 0.39	0.23 ± 0.32	0.00 ± 0.00	1.91 ± 2.69	4.78 ± 1.91
D-dimethylphenanthrene	2.67 ± 1.37	4.29 ± 1.06	2.59 ± 3.66	2.73 ± 1.95	0.00 ± 0.00	2.20 ± 3.11	2.74 ± 3.87
E-dimethylphenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C-dimethylphenanthrene	2.23 ± 3.15	2.33 ± 3.30	2.84 ± 4.01	2.21 ± 3.12	0.00 ± 0.00	2.11 ± 2.99	0.00 ± 0.00
Fluoranthene	0.00 ± 0.00	2.18 ± 3.08	4.74 ± 0.86	0.59 ± 0.84	0.00 ± 0.00	0.31 ± 0.43	0.29 ± 0.41
Pyrene	0.00 ± 0.00	4.02 ± 5.69	9.98 ± 0.01	3.20 ± 3.20	3.21 ± 4.54	0.90 ± 1.27	0.00 ± 0.00

9-Anthraaldehyde	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Retene	0.00 ± 0.00	0.00 ± 0.00	0.24 ± 0.35	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(a)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(b)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
5-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1-MeFl+C-MeFl/Py	0.00 ± 0.00	1.20 ± 1.70	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	3.13 ± 1.76
1+3-methylfluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
4-methylpyrene	3.50 ± 1.39	3.70 ± 1.36	8.55 ± 6.25	3.55 ± 2.87	1.32 ± 1.87	2.29 ± 0.99	3.71 ± 0.35
C-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
D-MePy/MeFl	1.07 ± 1.51	1.95 ± 2.76	1.35 ± 1.91	0.00 ± 0.00	0.00 ± 0.00	0.91 ± 1.29	2.32 ± 3.28
1-methylpyrene	4.06 ± 0.65	1.36 ± 1.92	3.22 ± 0.61	1.30 ± 1.83	0.00 ± 0.00	2.35 ± 0.54	2.70 ± 0.93
Benzonaphthothiophene	0.00 ± 0.00	0.74 ± 1.05	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.65 ± 0.92	0.00 ± 0.00
benzo(c)phenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(ghi)fluoranthene	2.27 ± 0.14	6.10 ± 2.95	9.35 ± 0.00	6.47 ± 0.63	1.24 ± 1.75	2.94 ± 1.39	2.82 ± 1.14
9-phenylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
6-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00 ± 0.00	0.41 ± 0.58	0.35 ± 0.50	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benz(a)anthracene	0.00 ± 0.00	0.22 ± 0.31	1.32 ± 1.86	0.23 ± 0.33	0.00 ± 0.00	0.26 ± 0.17	0.09 ± 0.12
Chrysene	1.33 ± 0.38	0.78 ± 0.67	3.97 ± 2.79	1.04 ± 0.66	0.80 ± 1.13	1.09 ± 0.25	0.67 ± 0.95
Benzanthrone	0.00 ± 0.00	1.46 ± 2.07	2.88 ± 4.07	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benz(a)anthracene-7,12-	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

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3-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7,12-dimethylbenz(a)anthracene	3.33 ± 0.28	4.12 ± 1.36	5.21 ± 0.21	5.19 ± 2.76	13.17 ± 3.80	2.52 ± 3.28	2.41 ± 3.41
Benzo(b)fluoranthene	0.53 ± 0.61	0.11 ± 0.05	4.04 ± 2.65	0.17 ± 0.24	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(j)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	2.45 ± 0.20	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(k)fluoranthene	1.03 ± 0.79	0.72 ± 1.01	1.01 ± 0.72	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(a)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BeP	0.39 ± 0.55	0.63 ± 0.47	2.43 ± 0.21	0.70 ± 0.06	0.22 ± 0.31	0.06 ± 0.08	0.02 ± 0.03
BaP	0.56 ± 0.79	1.46 ± 1.15	2.38 ± 0.55	0.00 ± 0.00	0.00 ± 0.00	0.31 ± 0.44	0.47 ± 0.26
Perylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylcholanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenzo(a)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]fluoranthene	0.77 ± 1.09	0.00 ± 0.00	1.10 ± 1.55	0.00 ± 0.00	0.00 ± 0.00	1.42 ± 0.23	0.00 ± 0.00
Indeno[123-cd]pyrene	1.02 ± 0.48	1.00 ± 1.42	2.77 ± 1.69	0.54 ± 0.76	0.00 ± 0.00	1.01 ± 0.28	0.00 ± 0.00
Dibenzo(ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah+ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Picene	4.85 ± 3.77	2.47 ± 3.49	7.95 ± 2.59	5.08 ± 7.18	1.39 ± 1.97	5.24 ± 7.41	1.76 ± 2.49
Benzo(ghi)perylene	3.46 ± 0.82	5.84 ± 2.57	8.22 ± 3.09	3.73 ± 0.17	2.34 ± 3.31	3.33 ± 0.11	1.63 ± 2.31
Anthanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Triphenylene	0.00 ± 0.00	0.00 ± 0.00	14.36 ± 20.30	14.06 ± 19.89	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,l)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00 ± 0.00	0.00 ± 0.00	2.61 ± 3.69	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,e)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table D10: Particle-phase PAH emissions for Vehicle #2

Component (ng/mile)	Fed ULSD	CARB USLD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Naphthalene	222.88 ± 249.37	303.88 ± 347.67	0.00 ± 0.00	24.63 ± 34.83	0.00 ± 0.00	4.14 ± 5.86	0.00 ± 0.00
Quinoline	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
2-methylnaphthalene	183.19 ± 192.93	298.53 ± 329.43	8.38 ± 11.85	22.85 ± 32.31	10.74 ± 8.38	4.75 ± 2.02	4.61 ± 6.52
1-methylnaphthalene	101.66 ± 100.01	149.81 ± 168.68	2.75 ± 3.89	11.90 ± 16.82	11.48 ± 11.12	3.65 ± 5.16	7.45 ± 10.54
Biphenyl	15.99 ± 22.62	17.74 ± 22.23	0.00 ± 0.00	1.17 ± 1.65	0.00 ± 0.00	5.34 ± 0.25	9.15 ± 12.94
2-methylbiphenyl	24.83 ± 12.97	24.20 ± 11.41	13.78 ± 3.31	13.54 ± 2.38	16.69 ± 1.57	14.71 ± 1.61	12.43 ± 0.59
2,6+2,7-dimethylnaphthalene	44.12 ± 37.48	62.25 ± 58.75	4.76 ± 6.74	10.56 ± 14.93	5.66 ± 2.46	3.73 ± 3.17	4.14 ± 5.85
1,3+1,6+1,7dimethylnaphth	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1,4+1,5+2,3-dimethylnaphth	35.66 ± 50.43	64.68 ± 91.47	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.27 ± 1.80

Acenaphthylene	0.00 ± 0.00	3.36 ± 4.75	7.50 ± 10.61	1.59 ± 2.25	1.97 ± 2.78	5.41 ± 3.19	1.65 ± 2.33
1,2-dimethylnaphthalene	20.14 ± 14.96	21.03 ± 11.37	7.10 ± 3.61	8.37 ± 0.16	3.00 ± 0.72	0.28 ± 0.39	2.09 ± 2.72
1,8-dimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthene	1.87 ± 2.65	3.85 ± 5.45	6.91 ± 3.06	3.55 ± 5.02	7.83 ± 0.05	6.35 ± 1.88	3.61 ± 0.34
3-methylbiphenyl	49.33 ± 41.99	51.89 ± 20.73	1.69 ± 2.39	37.38 ± 23.14	25.20 ± 1.22	13.71 ± 19.39	0.00 ± 0.00
4-methylbiphenyl	20.44 ± 17.47	39.31 ± 7.75	1.20 ± 1.70	25.85 ± 6.94	24.67 ± 2.14	12.82 ± 18.13	0.00 ± 0.00
1+2ethylnaphthalene	89.91 ± 50.32	197.85 ± 172.71	71.55 ± 58.57	61.88 ± 30.79	69.11 ± 3.69	31.65 ± 44.76	76.96 ± 5.97
1-ethyl-2-methylnaphthalene	2.77 ± 3.92	2.25 ± 3.18	4.04 ± 1.46	4.07 ± 1.79	3.96 ± 1.07	1.82 ± 2.58	0.00 ± 0.00
2,3,5+I-trimethylnaphthalene	11.86 ± 5.47	16.12 ± 3.74	7.79 ± 0.10	10.35 ± 3.14	9.59 ± 0.41	6.75 ± 0.73	4.53 ± 1.30
B-trimethylnaphthalene	18.35 ± 15.59	19.37 ± 13.20	24.55 ± 27.27	32.18 ± 35.29	6.59 ± 1.31	42.59 ± 6.67	1.26 ± 1.78
A-trimethylnaphthalene	9.27 ± 11.21	10.30 ± 14.57	0.14 ± 0.20	0.50 ± 0.71	0.59 ± 0.84	0.00 ± 0.00	0.00 ± 0.00
C-trimethylnaphthalene	10.25 ± 14.47	15.72 ± 20.49	0.00 ± 0.00	2.20 ± 1.52	0.20 ± 0.28	0.00 ± 0.00	0.00 ± 0.00
2-ethyl-1-methylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 1.42	1.11 ± 1.57	1.64 ± 2.32	2.79 ± 0.49	0.00 ± 0.00
E-trimethylnaphthalene	16.48 ± 15.38	24.24 ± 23.38	0.00 ± 0.00	5.07 ± 5.07	1.24 ± 1.75	0.00 ± 0.00	0.00 ± 0.00
2,4,5-trimethylnaphthalene	3.49 ± 4.94	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
F-trimethylnaphthalene	16.73 ± 12.10	14.79 ± 14.70	1.01 ± 1.43	0.15 ± 0.22	2.53 ± 1.63	4.94 ± 5.02	0.04 ± 0.06
Fluorene	7.81 ± 10.08	5.45 ± 7.71	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1,4,5-trimethylnaphthalene	77.37 ± 78.93	85.51 ± 72.13	10.44 ± 10.09	19.68 ± 10.76	11.26 ± 0.33	3.83 ± 5.41	0.00 ± 0.00
J-trimethylnaphthalene	7.48 ± 4.15	0.00 ± 0.00	4.91 ± 0.31	9.04 ± 1.65	4.82 ± 0.62	3.99 ± 0.39	3.99 ± 1.47
A-Methylfluorene	4.11 ± 1.68	11.97 ± 13.31	2.07 ± 2.93	16.12 ± 22.79	6.10 ± 4.03	3.80 ± 5.38	1.64 ± 2.32
B-Methylfluorene	6.74 ± 9.53	0.00 ± 0.00	7.74 ± 2.63	3.76 ± 5.32	0.00 ± 0.00	3.72 ± 5.26	2.46 ± 3.48
1-Methylfluorene	14.79 ± 11.16	8.46 ± 11.96	4.36 ± 4.52	7.63 ± 10.36	0.10 ± 0.14	7.55 ± 6.27	9.51 ± 5.52

9-fluorenone	12.85 ± 0.10	9.19 ± 3.54	9.67 ± 0.57	0.00 ± 0.00	8.19 ± 0.85	6.53 ± 3.94	2.88 ± 4.07
Dibenzothiophene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Phenanthrene	20.22 ± 18.46	35.82 ± 0.85	9.77 ± 4.62	35.20 ± 10.74	37.44 ± 2.96	17.57 ± 24.85	0.00 ± 0.00
Anthracene	5.17 ± 4.11	4.45 ± 2.36	1.26 ± 0.34	3.20 ± 0.93	0.83 ± 1.17	3.22 ± 1.41	0.51 ± 0.72
Xanthone	14.98 ± 3.80	13.94 ± 9.25	20.98 ± 2.99	12.63 ± 0.70	12.86 ± 2.55	12.18 ± 1.74	5.45 ± 1.95
1,4-Naphthoquinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthenequinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylphenanthrene	14.40 ± 10.24	13.90 ± 3.72	5.56 ± 1.90	9.39 ± 0.96	9.27 ± 1.73	5.51 ± 1.92	1.16 ± 1.63
2-methylphenanthrene	6.76 ± 6.26	10.37 ± 8.96	5.55 ± 7.84	5.72 ± 5.78	4.93 ± 0.03	4.54 ± 6.42	4.58 ± 6.45
Perinaphthenone	13.42 ± 18.98	24.38 ± 8.36	36.79 ± 2.39	24.86 ± 5.55	42.16 ± 3.28	26.34 ± 0.59	27.05 ± 1.69
2-methylanthracene	0.63 ± 0.89	0.00 ± 0.00	0.84 ± 1.19	0.00 ± 0.00	3.12 ± 1.02	1.88 ± 2.66	4.07 ± 1.43
4,5-methylenephenanthrene	0.00 ± 0.00	0.08 ± 0.12	0.00 ± 0.00	0.00 ± 0.00	0.36 ± 0.51	0.00 ± 0.00	0.00 ± 0.00
9-methylphenanthrene	3.38 ± 1.53	0.00 ± 0.00	4.62 ± 0.92	6.10 ± 2.27	4.62 ± 0.22	4.98 ± 7.05	1.26 ± 1.78
1-methylphenanthrene	12.15 ± 5.43	17.12 ± 0.56	9.46 ± 1.32	15.94 ± 1.82	14.05 ± 3.45	5.58 ± 7.89	3.14 ± 4.44
Anthrone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
9-methylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Anthraquinone	13.89 ± 0.68	12.12 ± 6.88	10.69 ± 4.75	17.92 ± 3.08	12.62 ± 5.16	7.25 ± 10.26	0.00 ± 0.00
A-dimethylphenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-dimethylphenanthrene	5.54 ± 7.83	11.35 ± 2.41	8.44 ± 4.39	7.82 ± 0.36	8.02 ± 2.90	6.54 ± 0.65	9.55 ± 4.16
1,7-dimethylphenanthrene	0.00 ± 0.00	4.13 ± 5.84	0.00 ± 0.00	0.00 ± 0.00	2.11 ± 2.99	1.75 ± 2.48	0.00 ± 0.00
3,6-dimethylphenanthrene	4.10 ± 5.80	2.15 ± 3.05	1.80 ± 2.54	0.38 ± 0.54	0.00 ± 0.00	3.20 ± 4.53	2.95 ± 2.48
D-dimethylphenanthrene	7.14 ± 4.55	5.01 ± 7.08	4.55 ± 1.01	1.69 ± 2.39	5.36 ± 0.96	0.71 ± 1.00	0.00 ± 0.00

E-dimethylphenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C-dimethylphenanthrene	0.00 ± 0.00	5.87 ± 8.31	0.00 ± 0.00	0.00 ± 0.00	4.39 ± 0.28	2.54 ± 3.59	0.00 ± 0.00
Fluoranthene	4.93 ± 4.18	4.60 ± 3.41	3.48 ± 3.74	1.56 ± 1.28	1.43 ± 0.96	1.10 ± 1.56	0.00 ± 0.00
Pyrene	8.08 ± 9.42	12.18 ± 6.25	5.01 ± 7.09	5.69 ± 2.92	6.46 ± 2.49	2.63 ± 3.72	0.00 ± 0.00
9-Anthraaldehyde	0.00 ± 0.00	0.00 ± 0.00	16.68 ± 23.58	0.00 ± 0.00	4.95 ± 6.99	0.00 ± 0.00	0.00 ± 0.00
Retene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.19 ± 0.27	0.20 ± 0.28	0.11 ± 0.15	0.00 ± 0.00
benzo(a)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(b)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
5-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1-MeFl+C-MeFl/Py	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.42 ± 3.42	0.00 ± 0.00	0.00 ± 0.00
1+3-methylfluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
4-methylpyrene	4.17 ± 2.43	6.27 ± 0.18	4.12 ± 0.88	2.01 ± 2.84	5.44 ± 2.34	5.72 ± 0.51	4.88 ± 4.00
C-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
D-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1-methylpyrene	5.17 ± 1.74	4.13 ± 0.83	4.62 ± 0.80	0.00 ± 0.00	2.56 ± 1.45	0.00 ± 0.00	1.56 ± 2.21
Benzonaphthothiophene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(c)phenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(ghi)fluoranthene	9.45 ± 4.88	7.88 ± 0.06	7.37 ± 0.82	6.31 ± 3.10	4.56 ± 0.28	7.86 ± 4.82	4.23 ± 1.37
9-phenylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
6-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Benz(a)anthracene	0.00 ± 0.00	1.03 ± 1.45	0.00 ± 0.00	0.02 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	0.05 ± 0.07
Chrysene	1.35 ± 1.91	1.59 ± 0.19	1.36 ± 0.03	0.00 ± 0.00	0.59 ± 0.83	0.52 ± 0.74	1.12 ± 0.20
Benzanthrone	2.54 ± 3.59	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.66 ± 2.34	0.00 ± 0.00	1.04 ± 1.46
Benz(a)anthracene-7,12-dione	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7,12-dimethylbenz(a)anthracene	2.75 ± 3.88	7.64 ± 1.67	6.50 ± 0.63	3.96 ± 5.60	8.86 ± 7.75	6.05 ± 2.97	13.86 ± 1.42
Benzo(b)fluoranthene	0.67 ± 0.69	1.06 ± 0.75	1.45 ± 0.37	0.33 ± 0.47	0.00 ± 0.00	0.28 ± 0.39	0.00 ± 0.00
Benzo(j)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.51 ± 0.72	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(a)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BeP	2.08 ± 0.95	1.48 ± 0.11	0.87 ± 0.64	0.89 ± 0.05	0.33 ± 0.24	0.66 ± 0.24	0.03 ± 0.04
BaP	0.66 ± 0.94	0.00 ± 0.00	1.12 ± 0.81	0.00 ± 0.00	0.57 ± 0.26	0.78 ± 0.05	0.51 ± 0.72
Perylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylcholanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenzo(a)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]fluoranthene	0.63 ± 0.89	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.60 ± 0.02	1.77 ± 0.56	1.24 ± 0.67
Indeno[123-cd]pyrene	0.18 ± 0.15	0.07 ± 0.00	0.07 ± 0.00	0.08 ± 0.00	0.58 ± 0.01	0.39 ± 0.12	0.28 ± 0.15
Dibenzo(ac)anthracene	1.41 ± 2.00	0.00 ± 0.00	0.70 ± 0.99	0.00 ± 0.00	1.43 ± 0.18	0.41 ± 0.58	0.50 ± 0.70
Dibenzo(ah+ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Dibenzo(ah)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Picene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(ghi)perylene	9.31 ± 3.64	13.63 ± 1.79	10.18 ± 8.20	4.53 ± 2.46	19.07 ± 6.83	5.72 ± 8.09	4.51 ± 1.94
Anthanthrene	6.27 ± 0.04	6.61 ± 1.66	5.34 ± 0.78	5.63 ± 0.31	5.40 ± 3.00	3.93 ± 1.00	3.75 ± 0.26
Triphenylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,l)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,e)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table D11: Particle-phase PAH emissions for Vehicle #3

Component (ng/mile)	Fed ULSD	CARB USLD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
Naphthalene	0.25 ± 0.35	1.02 ± 1.44	7.84 ± 6.25	2.23 ± 3.15	0.00 ± 0.00	6.22 ± 8.79	38.16 ± 46.80
Quinoline	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
2-methylnaphthalene	5.52 ± 4.45	3.75 ± 5.30	13.80 ± 13.80	9.40 ± 11.60	0.67 ± 0.40	10.02 ± 14.18	35.93 ± 42.24
1-methylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	2.11 ± 2.99	0.22 ± 0.31	0.00 ± 0.00	5.45 ± 7.70	20.02 ± 28.31
Biphenyl	0.00 ± 0.00	0.00 ± 0.00	0.91 ± 1.29	0.22 ± 0.31	0.46 ± 0.65	3.38 ± 4.77	14.39 ± 20.00
2-methylbiphenyl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.34 ± 0.48

2,6+2,7-dimethylnaphthalene	2.03 ± 0.07	1.05 ± 0.51	2.69 ± 2.57	1.53 ± 1.49	0.72 ± 0.84	2.46 ± 2.35	11.10 ± 12.12
1,3+1,6+1,7dimethylnaphth	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1,4+1,5+2,3-dimethylnaphth	10.01 ± 8.51	16.22 ± 4.28	23.24 ± 6.95	19.82 ± 0.46	43.69 ± 12.83	22.01 ± 0.90	33.21 ± 18.95
Acenaphthylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.34 ± 0.48	0.00 ± 0.00
1,2-dimethylnaphthalene	2.58 ± 1.46	2.35 ± 0.86	2.89 ± 1.08	3.30 ± 0.16	1.49 ± 2.11	2.21 ± 3.12	11.61 ± 11.99
1,8-dimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.42 ± 2.00	1.33 ± 1.87	0.00 ± 0.00	0.00 ± 0.00
Acenaphthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylbiphenyl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.66 ± 0.93	4.05 ± 5.72
4-methylbiphenyl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.03 ± 0.04	0.34 ± 0.49	0.93 ± 1.31
1+2ethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1-ethyl-2-methylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
2,3,5+I-trimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-trimethylnaphthalene	0.26 ± 0.37	0.00 ± 0.00	0.00 ± 0.00	0.22 ± 0.26	0.66 ± 0.01	0.24 ± 0.33	0.30 ± 0.43
A-trimethylnaphthalene	1.40 ± 1.98	0.66 ± 0.84	0.00 ± 0.00	0.95 ± 1.35	0.45 ± 0.30	0.00 ± 0.00	0.00 ± 0.00
C-trimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.06 ± 1.49	1.13 ± 1.60	0.00 ± 0.00
2-ethyl-1-methylnaphthalene	0.11 ± 0.15	0.00 ± 0.00	0.03 ± 0.04	0.41 ± 0.58	1.27 ± 0.18	0.90 ± 1.28	0.00 ± 0.00
E-trimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
2,4,5-trimethylnaphthalene	0.60 ± 0.11	0.13 ± 0.18	0.34 ± 0.44	0.60 ± 0.84	0.10 ± 0.15	0.00 ± 0.00	0.60 ± 0.32
F-trimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Fluorene	0.58 ± 0.39	0.00 ± 0.00	0.30 ± 0.29	0.75 ± 0.84	0.59 ± 0.23	0.27 ± 0.03	0.00 ± 0.00
1,4,5-trimethylnaphthalene	19.04 ± 4.91	8.40 ± 5.25	7.59 ± 0.08	11.39 ± 3.77	0.03 ± 0.05	0.66 ± 0.93	6.95 ± 3.83
J-trimethylnaphthalene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

A-Methylfluorene	1.69 ± 1.07	0.38 ± 0.54	0.00 ± 0.00	0.66 ± 0.94	0.44 ± 0.62	1.12 ± 0.72	0.50 ± 0.42
B-Methylfluorene	2.04 ± 2.88	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.10 ± 0.14	0.70 ± 0.99	2.74 ± 2.54
1-Methylfluorene	0.92 ± 0.13	0.00 ± 0.00	0.00 ± 0.00	0.04 ± 0.06	0.00 ± 0.00	1.16 ± 1.64	1.17 ± 1.24
9-fluorenone	1.01 ± 0.60	0.00 ± 0.00	1.08 ± 1.35	2.59 ± 1.27	1.76 ± 1.17	2.00 ± 0.07	2.45 ± 0.17
Dibenzothiophene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Phenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.13 ± 0.63	0.00 ± 0.00	0.30 ± 0.42	1.25 ± 0.64
Anthracene	0.13 ± 0.18	0.27 ± 0.38	0.86 ± 0.39	0.55 ± 0.16	0.08 ± 0.12	0.43 ± 0.60	0.96 ± 0.64
Xanthone	3.48 ± 0.72	5.64 ± 2.48	4.85 ± 0.38	7.44 ± 3.39	4.98 ± 2.38	2.98 ± 0.13	4.88 ± 0.03
1,4-Naphthoquinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthenequinone	0.28 ± 0.09	0.00 ± 0.00	0.65 ± 0.92	2.98 ± 4.21	2.34 ± 3.31	0.34 ± 0.48	2.88 ± 1.84
3-methylphenanthrene	1.50 ± 0.96	1.12 ± 0.57	0.95 ± 0.74	3.09 ± 0.70	2.47 ± 2.40	1.45 ± 0.86	0.58 ± 0.43
2-methylphenanthrene	0.90 ± 1.27	0.00 ± 0.00	0.53 ± 0.19	3.71 ± 0.66	0.00 ± 0.00	0.21 ± 0.30	0.95 ± 0.53
Perinaphthenone	3.44 ± 4.86	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.39 ± 0.55
2-methylanthracene	0.00 ± 0.00	0.00 ± 0.00	2.15 ± 3.05	1.99 ± 2.81	0.00 ± 0.00	0.00 ± 0.00	4.29 ± 6.07
4,5-methylenephenanthrene	3.16 ± 0.41	2.26 ± 0.36	0.83 ± 0.12	3.38 ± 0.96	0.68 ± 0.97	2.59 ± 0.22	1.15 ± 0.41
9-methylphenanthrene	0.15 ± 0.21	0.01 ± 0.02	0.00 ± 0.00	1.22 ± 0.76	0.57 ± 0.80	0.31 ± 0.44	0.19 ± 0.26
1-methylphenanthrene	0.49 ± 0.64	0.18 ± 0.25	0.25 ± 0.35	1.53 ± 0.53	0.00 ± 0.00	0.80 ± 1.12	1.06 ± 0.84
Anthrone	7.82 ± 1.51	4.38 ± 6.19	0.00 ± 0.00	8.62 ± 0.07	0.00 ± 0.00	0.00 ± 0.00	1.46 ± 2.06
9-methylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Anthraquinone	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
A-dimethylphenanthrene	1.18 ± 0.03	1.38 ± 1.95	0.27 ± 0.38	2.95 ± 1.47	0.00 ± 0.00	0.90 ± 1.28	0.90 ± 1.27
B-dimethylphenanthrene	1.07 ± 0.24	0.00 ± 0.00	0.00 ± 0.00	1.60 ± 0.52	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

1,7-dimethylphenanthrene	1.16 ± 0.58	0.00 ± 0.00	1.24 ± 1.75	0.69 ± 0.12	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3,6-dimethylphenanthrene	0.65 ± 0.88	0.08 ± 0.12	0.62 ± 0.87	1.30 ± 0.72	0.00 ± 0.00	0.00 ± 0.00	1.50 ± 1.01
D-dimethylphenanthrene	1.40 ± 1.99	0.00 ± 0.00	0.00 ± 0.00	2.10 ± 1.37	0.00 ± 0.00	0.00 ± 0.00	1.28 ± 1.03
E-dimethylphenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
C-dimethylphenanthrene	2.71 ± 0.15	0.00 ± 0.00	5.19 ± 3.34	8.01 ± 2.71	2.42 ± 0.90	1.21 ± 0.05	1.00 ± 1.41
Fluoranthene	0.28 ± 0.39	0.00 ± 0.00	0.00 ± 0.00	4.60 ± 0.02	0.49 ± 0.69	0.00 ± 0.00	0.13 ± 0.18
Pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	7.54 ± 0.80	0.58 ± 0.82	0.00 ± 0.00	0.27 ± 0.39
9-Anthraaldehyde	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Retene	0.00 ± 0.00	0.01 ± 0.02	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(a)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(b)fluorene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
5-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
B-MePy/MeFl	0.49 ± 0.69	0.00 ± 0.00	0.00 ± 0.00	0.66 ± 0.93	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1-MeFl+C-MeFl/Py	0.28 ± 0.39	0.62 ± 0.88	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
1+3-methylfluoranthene	0.27 ± 0.38	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
4-methylpyrene	0.15 ± 0.21	0.11 ± 0.15	0.31 ± 0.44	2.36 ± 0.01	0.00 ± 0.00	0.05 ± 0.07	0.00 ± 0.00
C-MePy/MeFl	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
D-MePy/MeFl	1.43 ± 0.37	0.00 ± 0.00	0.63 ± 0.89	4.03 ± 0.36	0.00 ± 0.00	0.95 ± 1.35	1.27 ± 0.23
1-methylpyrene	0.08 ± 0.12	0.00 ± 0.00	0.05 ± 0.07	1.42 ± 0.29	0.00 ± 0.00	0.20 ± 0.28	0.00 ± 0.00
Benzonaphthothiophene	0.37 ± 0.25	0.25 ± 0.35	0.14 ± 0.20	0.96 ± 0.77	0.78 ± 1.10	1.29 ± 0.60	0.47 ± 0.53
benzo(c)phenanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(ghi)fluoranthene	0.07 ± 0.10	0.00 ± 0.00	0.04 ± 0.06	2.32 ± 1.95	0.08 ± 0.11	0.14 ± 0.04	1.09 ± 1.00

9-phenylanthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
6-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.11	0.44 ± 0.17	0.00 ± 0.00	0.27 ± 0.38	0.04 ± 0.06
Benz(a)anthracene	0.94 ± 0.17	0.00 ± 0.00	0.57 ± 0.29	0.67 ± 0.13	0.00 ± 0.00	0.35 ± 0.49	0.47 ± 0.66
Chrysene	1.41 ± 0.42	0.34 ± 0.15	0.83 ± 0.82	1.75 ± 0.12	0.00 ± 0.00	1.14 ± 0.28	0.92 ± 1.31
Benzanthrone	0.71 ± 1.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benz(a)anthracene-7,12-dione	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylchrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.28 ± 0.40	0.00 ± 0.00	0.39 ± 0.15	0.00 ± 0.00
7-methylbenz(a)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7,12-dimethylbenz(a)anthracene	0.00 ± 0.00	0.88 ± 0.63	0.91 ± 1.28	0.00 ± 0.00	1.09 ± 1.54	0.81 ± 0.17	0.85 ± 1.17
Benzo(b)fluoranthene	0.50 ± 0.24	0.18 ± 0.14	0.18 ± 0.20	0.30 ± 0.43	0.26 ± 0.36	0.23 ± 0.01	0.28 ± 0.03
Benzo(j)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.78 ± 1.10
Benzo(k)fluoranthene	0.00 ± 0.00	0.04 ± 0.05	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(a)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
BeP	0.09 ± 0.12	0.02 ± 0.02	0.17 ± 0.02	0.12 ± 0.07	0.02 ± 0.03	0.23 ± 0.27	0.13 ± 0.02
BaP	0.09 ± 0.13	0.17 ± 0.24	0.18 ± 0.05	0.10 ± 0.15	0.00 ± 0.00	0.24 ± 0.09	0.21 ± 0.03
Perylene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylcholanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenzo(a)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Indeno[123-cd]pyrene	0.00 ± 0.00	0.17 ± 0.24	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah+ac)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Picene	0.48 ± 0.20	1.00 ± 0.27	0.00 ± 0.00	0.00 ± 0.00	0.20 ± 0.28	0.54 ± 0.76	0.00 ± 0.00
Benzo(ghi)perylene	0.29 ± 0.42	0.35 ± 0.49	0.26 ± 0.30	0.47 ± 0.46	0.12 ± 0.17	0.62 ± 0.11	0.32 ± 0.02
Anthanthrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Triphenylene	0.22 ± 0.32	0.00 ± 0.00	0.00 ± 0.00	0.53 ± 0.14	0.28 ± 0.39	0.00 ± 0.00	0.97 ± 1.37
Dibenzo(a,l)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,e)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Table D12: Particle-phase PAH emissions for Vehicle #4

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	80.10± 93.20	18.99± 10.61	36.56± 21.92	113.79± 57.62	66.49± 85.13	7.31± 0.82	98.24± 95.73
quinoline	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	13.45± 16.06	0.00± 0.00	0.00± 0.00
2-methylnaphthalene	58.75± 62.26	16.06± 4.25	33.14± 17.08	118.41± 84.53	57.25± 74.30	12.57± 6.78	112.72± 107.28
1-methylnaphthalene	33.72± 37.28	8.17± 2.69	17.62± 9.28	57.22± 37.27	34.56± 45.17	4.97± 1.16	72.17± 79.71
Biphenyl	49.53± 49.96	19.24± 8.75	23.68± 7.42	77.04± 44.93	40.60± 38.88	7.04± 1.77	22.65± 0.00

2-methylbiphenyl	137.79± 140.57	51.88± 14.29	58.67± 5.64	132.80± 61.96	122.41± 35.16	22.92± 9.35	57.94± 0.00
2,6+2,7-dimethylnaphthalene	19.23± 18.27	6.85± 1.56	15.78± 11.15	57.22± 38.01	31.93± 42.19	5.23± 1.53	62.42± 65.19
1,3+1,6+1,7dimethylnaphth	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,4+1,5+2,3-dimethylnaphth	24.76± 24.61	9.48± 1.58	15.26± 8.17	55.87± 30.27	38.74± 30.31	5.74± 0.06	81.91± 93.49
Acenaphthylene	21.60± 21.63	7.10± 0.44	10.79± 0.38	19.26± 3.24	21.33± 8.65	4.16± 2.17	42.93± 46.56
1,2-dimethylnaphthalene	10.27± 9.32	2.38± 3.37	4.47± 6.32	46.24± 29.75	21.37± 25.77	2.88± 1.88	20.81± 8.57
1,8-dimethylnaphthalene	5.01± 5.59	0.78± 1.11	1.31± 1.86	23.28± 15.82	3.69± 2.25	1.04± 0.01	12.38± 12.29
Acenaphthene	4.22± 4.47	0.79± 0.38	6.05± 7.06	29.24± 16.62	20.06± 28.37	2.10± 1.50	1.32± 1.86
3-methylbiphenyl	129.35± 122.68	49.72± 3.11	72.09± 6.63	174.95± 100.47	134.26± 41.53	25.53± 8.58	63.20± 0.00
4-methylbiphenyl	63.75± 59.66	24.47± 2.11	35.52± 3.31	83.85± 51.65	66.61± 22.25	12.51± 4.29	32.13± 0.00
1+2ethylnaphthalene	28.98± 30.57	9.48± 2.33	14.21± 4.45	42.07± 27.48	27.41± 23.94	5.22± 0.06	75.85± 84.93
1-ethyl-2-methylnaphthalene	3.94± 5.58	7.36± 0.07	9.73± 3.34	34.86± 36.93	28.22± 29.52	4.21± 5.95	34.50± 45.07
2,3,5+I-trimethylnaphthalene	6.85± 5.97	2.63± 0.77	7.63± 7.06	25.58± 13.63	16.88± 20.91	3.14± 1.51	16.33± 9.69
B-trimethylnaphthalene	9.75± 7.83	3.94± 0.33	11.31± 11.52	40.27± 30.03	27.18± 38.44	4.19± 2.26	5.00± 7.08
A-trimethylnaphthalene	6.06± 7.08	1.32± 0.39	3.42± 2.60	16.14± 2.45	8.70± 9.34	1.31± 0.38	20.54± 24.58
C-trimethylnaphthalene	15.81± 14.92	5.00± 0.42	13.41± 11.52	44.69± 30.46	26.12± 33.23	4.44± 1.16	48.99± 50.66
2-ethyl-1-methylnaphthalene	0.00± 0.00	0.26± 0.37	0.53± 0.74	2.09± 0.77	0.79± 1.12	0.26± 0.37	0.00± 0.00
E-trimethylnaphthalene	3.69± 2.98	1.32± 0.39	3.42± 4.83	10.72± 7.88	33.25± 46.28	2.62± 2.24	6.85± 2.98
2,4,5-trimethylnaphthalene	0.79± 1.12	1.32± 0.39	3.68± 3.72	10.72± 7.88	8.70± 8.60	2.36± 1.87	19.49± 18.62
F-trimethylnaphthalene	17.12± 15.29	4.47± 0.42	14.73± 8.17	47.49± 23.52	34.57± 45.92	4.45± 1.89	44.51± 46.56
Fluorene	20.29± 20.51	7.64± 2.68	17.62± 16.73	72.34± 43.39	49.87± 66.82	7.32± 1.56	86.12± 103.18
1,4,5-trimethylnaphthalene	0.53± 0.74	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
J-trimethylnaphthalene	0.00± 0.00	0.26± 0.37	2.10± 2.23	6.04± 8.55	5.81± 8.21	1.57± 0.02	1.05± 0.00
A-Methylfluorene	26.08± 28.71	7.10± 0.44	9.47± 0.73	27.39± 12.55	22.39± 12.38	3.91± 0.33	9.48± 0.00
B-Methylfluorene	0.26± 0.37	0.00± 0.00	1.05± 1.49	2.10± 2.97	0.52± 0.74	0.00± 0.00	0.00± 0.00
1-Methylfluorene	10.54± 11.18	2.10± 0.02	3.95± 2.60	16.98± 10.19	13.45± 16.80	2.35± 0.39	4.21± 0.00
9-fluorenone	10.01± 10.44	2.90± 1.15	6.84± 2.23	22.97± 12.12	10.81± 12.33	1.57± 0.02	2.63± 0.00
Dibenzothiophene	7.38± 7.46	2.37± 0.40	3.16± 1.49	15.13± 6.11	10.54± 6.74	2.09± 0.02	4.21± 0.00
Phenanthrene	88.53± 105.87	16.87± 6.87	28.14± 23.41	143.68± 23.52	117.94± 154.93	22.99± 3.20	26.33± 0.00
Anthracene	26.09± 32.43	5.28± 3.03	6.31± 1.48	21.64± 8.79	52.25± 71.67	4.18± 1.52	11.59± 0.00

Xanthone	2.37± 1.12	1.06± 0.75	6.05± 3.35	3.64± 0.06	111.90± 156.76	6.31± 8.19	0.53± 0.00
1,4-Naphthoquinone	26.87± 18.66	14.72± 2.08	16.31± 0.02	9.00± 12.73	14.21± 0.81	15.66± 0.57	7.90± 11.17
Acenaphthenequinone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-methylphenanthrene	10.28± 12.30	2.11± 1.51	2.63± 2.23	12.22± 0.55	12.14± 15.68	2.35± 0.34	2.11± 0.00
2-methylphenanthrene	12.65± 14.91	2.37± 1.14	4.47± 1.86	16.90± 0.63	19.79± 25.76	1.81± 2.56	3.69± 0.00
Perinaphthenone	152.87± 91.71	667.08± 746.93	208.59± 103.60	338.46± 98.19	172.22± 76.68	59.17± 33.12	59.52± 0.00
2-methylanthracene	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4,5-methylenephenanthrene	2.90± 3.36	0.53± 0.01	1.05± 0.74	4.16± 0.06	3.96± 4.85	0.52± 0.01	1.05± 0.00
9-methylphenanthrene	5.27± 5.96	0.79± 0.38	1.58± 1.49	6.50± 0.27	7.65± 10.08	1.04± 0.01	2.11± 0.00
1-methylphenanthrene	5.53± 6.34	1.06± 0.75	1.31± 1.11	7.03± 1.21	6.07± 7.84	1.04± 0.01	1.05± 0.00
Anthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	11.83± 16.73	4.46± 6.30	0.00± 0.00	0.00± 0.00
9-methylanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Anthraquinone	4.48± 2.61	1.31± 0.36	2.63± 0.75	17.28± 15.71	2.64± 2.99	0.26± 0.37	2.63± 3.72
A-dimethylphenanthrene	0.00± 0.00	0.53± 0.01	0.53± 0.74	3.63± 0.68	2.64± 3.73	0.79± 0.38	0.00± 0.00
B-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.53± 0.75	0.26± 0.37	0.00± 0.00
1,7-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	1.84± 2.60	0.00± 0.00	0.00± 0.00
3,6-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.00± 0.00
D-dimethylphenanthrene	20.82± 29.44	1.84± 0.39	0.00± 0.00	0.00± 0.00	1.84± 2.60	0.00± 0.00	0.00± 0.00
E-dimethylphenanthrene	2.90± 3.36	0.53± 0.01	0.53± 0.00	1.54± 2.18	0.26± 0.37	0.52± 0.01	0.00± 0.00
C-dimethylphenanthrene	0.26± 0.37	0.26± 0.37	0.00± 0.00	1.54± 2.18	0.00± 0.00	0.00± 0.00	1.05± 0.00
Fluoranthene	8.96± 8.95	2.11± 0.77	2.89± 1.86	11.43± 1.30	11.08± 12.70	2.61± 0.03	2.63± 0.00
Pyrene	11.33± 13.79	2.63± 0.77	2.89± 1.11	11.13± 6.08	13.72± 16.43	3.13± 0.70	2.63± 0.00
9-Anthraaldehyde	1.58± 2.23	1.58± 0.02	2.89± 1.11	6.57± 9.29	0.79± 1.11	2.61± 0.03	0.00± 0.00
Retene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00
benzo(a)fluorene	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.00± 0.00
benzo(b)fluorene	0.79± 1.12	0.26± 0.37	0.00± 0.00	0.00± 0.00	0.53± 0.75	0.00± 0.00	0.00± 0.00
5-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
B-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-MeFl+C-MeFl/Py	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1+3-methylfluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

4-methylpyrene	1.32± 1.12	0.53± 0.01	1.58± 0.75	1.03± 1.45	0.79± 1.12	0.78± 0.36	#DIV/0!
C-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!
D-MePy/MeFl	0.00± 0.00	0.00± 0.00	1.05± 1.49	0.00± 0.00	0.53± 0.75	0.26± 0.37	#DIV/0!
1-methylpyrene	0.53± 0.75	0.00± 0.00	0.79± 1.12	0.00± 0.00	0.79± 1.12	0.26± 0.37	#DIV/0!
Benzonaphthothiophene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
benzo(c)phenanthrene	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(ghi)fluoranthene	1.05± 0.75	0.53± 0.01	1.32± 1.86	0.00± 0.00	0.26± 0.37	2.10± 2.24	0.00± 0.00
9-phenylanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Cyclopenta(c,d)pyrene	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.51± 0.73	0.26± 0.37	0.00± 0.00	0.00± 0.00
Benz(a)anthracene	1.32± 1.12	0.00± 0.00	0.79± 0.37	0.00± 0.00	0.53± 0.75	0.00± 0.00	0.00± 0.00
Chrysene	1.58± 1.49	0.53± 0.01	1.05± 0.75	0.77± 1.09	1.32± 1.12	0.52± 0.01	0.53± 0.00
Benzanthrone	0.00± 0.00	0.00± 0.00	0.53± 0.74	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benz(a)anthracene-7,12-dione	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-methylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7,12-dimethylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)fluoranthene	0.26± 0.37	0.53± 0.01	0.79± 1.12	0.51± 0.73	0.79± 1.12	0.53± 0.74	0.26± 0.37
Benzo(j)fluoranthene	0.00± 0.00	0.26± 0.37	0.53± 0.74	1.03± 1.45	0.26± 0.37	0.53± 0.74	0.53± 0.74
Benzo(k)fluoranthene	0.00± 0.00	0.26± 0.37	0.53± 0.74	0.00± 0.00	0.00± 0.00	0.79± 1.12	0.26± 0.37
Benzo(a)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
BeP	0.26± 0.37	0.79± 0.38	1.32± 1.12	1.05± 1.49	0.00± 0.00	0.53± 0.74	0.26± 0.37
BaP	0.26± 0.37	0.79± 0.38	0.79± 1.12	1.58± 2.23	0.26± 0.37	0.26± 0.37	0.00± 0.00
Perylene	0.00± 0.00	0.26± 0.37	0.26± 0.37	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.00± 0.00
3-methylcholanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-methylbenzo(a)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	7.62± 10.78	0.00± 0.00	0.00± 0.00	0.00± 0.00
Indeno[123-cd]fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	1.31± 1.86	0.53± 0.75	0.00± 0.00	0.00± 0.00
Indeno[123-cd]pyrene	0.00± 0.00	0.53± 0.01	0.79± 0.37	0.51± 0.73	1.32± 1.12	0.26± 0.37	1.58± 1.49

Dibenzo(ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah+ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah)anthracene	0.00± 0.00	0.53± 0.01	0.53± 0.74	0.00± 0.00	1.32± 1.87	0.26± 0.37	0.26± 0.37
Dibenzo(a,j)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.79± 1.12	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)chrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Picene	0.00± 0.00	0.26± 0.37	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(ghi)perylene	0.26± 0.37	0.79± 0.38	1.84± 1.86	1.56± 0.02	2.37± 2.62	0.79± 0.38	3.42± 4.10
Anthanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Triphenylene	0.26± 0.37	0.00± 0.00	0.26± 0.37	0.51± 0.73	0.53± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,l)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Coronene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.37	0.00± 0.00
Dibenzo(a,e)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,i)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,h)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(b,k)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D13: Particle-phase PAH emissions for Vehicle #5

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	18.84± 15.75	98.40± 85.12	19.43± 8.71	23.08± 6.72	52.82± 0.00	67.50± 35.41	25.55± 19.52
quinoline	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	1.01± 1.44	0.51± 0.72	0.00± 0.00
2-methylnaphthalene	17.85± 6.37	136.95± 125.43	19.67± 2.49	13.04± 1.87	67.50± 56.68	14.48± 2.67	26.27± 22.79
1-methylnaphthalene	9.95± 3.90	70.37± 59.00	11.24± 2.14	8.37± 2.17	44.92± 40.54	7.41± 0.36	14.02± 12.28
Biphenyl	13.51± 6.04	73.36± 58.24	19.68± 3.29	7.87± 0.77	66.24± 24.02	19.23± 3.19	19.99± 12.40
2-methylbiphenyl	29.04± 19.29	107.47± 95.82	21.47± 5.10	27.60± 10.71	174.59± 195.19	60.98± 28.36	45.63± 14.67
2,6+2,7-dimethylnaphthalene	7.91± 1.03	69.12± 60.07	10.73± 0.02	6.89± 0.07	21.83± 5.73	6.63± 0.69	14.99± 15.91
1,3+1,6+1,7dimethylnaphth	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,4+1,5+2,3-dimethylnaphth	10.70± 6.42	57.09± 47.32	13.29± 0.69	7.38± 0.77	23.35± 2.86	10.63± 2.01	15.09± 10.77
Acenaphthylene	5.35± 3.21	7.04± 0.00	4.60± 0.73	4.93± 1.44	7.36± 2.52	8.38± 3.34	9.01± 3.67
1,2-dimethylnaphthalene	6.36± 6.09	3.27± 4.62	13.80± 3.64	4.44± 3.52	10.92± 1.80	5.40± 4.75	4.85± 3.84
1,8-dimethylnaphthalene	0.26± 0.36	6.16± 3.74	10.47± 1.78	2.22± 1.07	13.71± 5.03	3.23± 2.40	2.05± 1.39

Acenaphthene	5.10± 2.13	14.08± 0.00	7.15± 0.02	3.19± 1.71	17.01± 1.09	1.57± 0.67	5.57± 7.11
3-methylbiphenyl	35.68± 19.97	62.84± 0.00	26.83± 2.59	29.56± 8.64	190.07± 198.41	66.79± 27.89	61.39± 30.91
4-methylbiphenyl	17.59± 8.90	30.67± 0.00	14.82± 2.20	15.02± 3.98	97.70± 102.26	35.84± 16.68	29.80± 14.94
1+2ethylnaphthalene	8.92± 5.35	17.09± 0.00	9.96± 2.51	7.14± 1.81	20.05± 11.84	9.02± 1.18	13.56± 9.36
1-ethyl-2-methylnaphthalene	1.54± 2.18	0.00± 0.00	6.12± 8.66	4.21± 5.96	7.61± 10.77	6.28± 2.69	3.74± 5.29
2,3,5+I-trimethylnaphthalene	4.08± 1.41	12.07± 0.00	9.45± 0.34	4.93± 1.44	13.20± 3.58	4.82± 2.48	8.38± 8.84
B-trimethylnaphthalene	4.85± 0.33	16.09± 0.00	9.97± 0.38	5.41± 0.64	16.24± 5.02	3.98± 0.57	11.17± 12.03
A-trimethylnaphthalene	2.80± 1.79	5.03± 0.00	4.09± 1.45	1.72± 0.37	6.35± 2.51	3.20± 0.90	3.81± 3.88
C-trimethylnaphthalene	6.63± 2.12	20.61± 0.00	15.58± 6.83	6.89± 0.76	21.32± 7.17	5.61± 2.14	12.97± 13.05
2-ethyl-1-methylnaphthalene	0.26± 0.36	0.25± 0.36	0.00± 0.00	0.49± 0.00	0.76± 0.36	0.00± 0.00	0.27± 0.38
E-trimethylnaphthalene	3.07± 0.74	5.53± 0.00	4.09± 0.71	2.46± 0.72	7.87± 3.94	2.15± 1.60	5.61± 4.91
2,4,5-trimethylnaphthalene	2.04± 0.71	6.03± 0.00	9.72± 6.53	4.44± 3.52	15.48± 0.37	5.15± 5.11	3.78± 5.35
F-trimethylnaphthalene	6.12± 1.40	18.10± 0.00	10.47± 1.78	5.66± 0.40	18.02± 8.25	5.04± 0.62	12.70± 13.43
Fluorene	11.47± 5.33	35.19± 0.00	17.38± 0.04	13.03± 1.61	33.76± 15.42	10.03± 1.01	16.26± 16.96
1,4,5-trimethylnaphthalene	0.00± 0.00	1.96± 2.77	0.00± 0.00	0.00± 0.00	1.52± 0.00	0.00± 0.00	0.00± 0.00
J-trimethylnaphthalene	0.26± 0.36	5.39± 6.91	4.35± 1.09	0.98± 0.01	5.84± 0.36	1.90± 1.96	1.01± 1.43
A-Methylfluorene	5.60± 4.29	9.55± 0.00	9.45± 0.34	6.90± 2.16	36.03± 36.60	9.33± 3.07	10.00± 5.83
B-Methylfluorene	1.03± 1.45	1.01± 0.00	3.06± 2.16	0.25± 0.35	0.76± 1.08	1.35± 1.19	7.87± 8.86
1-Methylfluorene	3.57± 2.14	7.54± 0.00	8.43± 3.96	3.44± 0.03	11.93± 6.10	3.20± 0.90	6.63± 5.60
9-fluorenone	3.31± 2.50	5.53± 0.00	6.39± 0.35	3.44± 0.03	21.06± 22.60	5.53± 0.86	4.10± 2.77
Dibenzothiophene	2.80± 1.79	4.02± 0.00	4.35± 1.09	3.20± 1.08	6.09± 0.71	2.89± 0.98	4.10± 2.77
Phenanthrene	29.03± 22.90	57.31± 0.00	53.14± 5.67	26.60± 7.22	85.02± 70.67	30.68± 10.87	34.25± 25.77
Anthracene	9.68± 6.43	14.08± 0.00	14.57± 4.01	7.41± 7.03	6.85± 5.39	8.97± 1.07	9.54± 2.92
Xanthone	4.61± 3.65	2.47± 0.65	2.30± 0.36	1.98± 2.11	25.88± 33.01	2.06± 2.14	1.29± 0.31
1,4-Naphthoquinone	15.07± 0.47	0.00± 0.00	11.75± 3.59	14.27± 1.53	9.65± 13.65	15.61± 0.38	0.80± 1.13
Acenaphthenequinone	0.00± 0.00	0.00± 0.00	1.79± 2.53	0.00± 0.00	0.76± 1.08	0.00± 0.00	0.00± 0.00
3-methylphenanthrene	2.80± 2.51	15.48± 15.49	10.47± 2.51	2.95± 0.73	8.63± 5.02	2.90± 0.23	3.59± 2.06
2-methylphenanthrene	3.56± 2.86	19.39± 21.03	13.28± 5.75	3.70± 1.78	13.45± 11.12	4.75± 0.52	4.11± 2.04
Perinaphthenone	118.35± 40.31	434.52± 155.93	201.57± 0.00	35.99± 16.36	159.35± 0.00	270.47± 124.65	61.90± 6.90
2-methylanthracene	0.00± 0.00	0.49± 0.69	2.55± 2.89	0.25± 0.35	0.00± 0.00	1.04± 0.70	0.00± 0.00

4,5-methylenephenanthrene	0.76± 1.08	3.69± 3.09	2.81± 1.08	0.74± 0.36	3.55± 2.87	1.57± 0.67	1.02± 0.69
9-methylphenanthrene	1.53± 1.43	8.35± 8.26	5.11± 2.16	1.23± 0.36	5.33± 4.66	1.84± 0.29	2.05± 1.39
1-methylphenanthrene	1.02± 0.71	7.62± 7.22	4.60± 2.16	1.48± 0.71	5.08± 4.30	1.57± 0.67	1.80± 1.03
Anthrone	4.62± 6.53	0.00± 0.00	4.35± 6.15	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9-methylanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Anthraquinone	2.04± 0.71	32.94± 30.94	5.11± 3.60	1.22± 1.73	2.79± 3.95	1.83± 1.03	7.82± 11.06
A-dimethylphenanthrene	1.02± 1.44	1.47± 2.08	3.06± 2.16	0.49± 0.00	1.02± 1.44	1.04± 0.70	0.76± 1.07
B-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.76± 1.08	0.00± 0.00	0.00± 0.00
1,7-dimethylphenanthrene	0.00± 0.00	0.50± 0.71	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00
3,6-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	1.53± 0.72	0.24± 0.35	1.78± 2.51	0.00± 0.00	0.00± 0.00
D-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	2.04± 2.89	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00
E-dimethylphenanthrene	0.25± 0.36	1.72± 1.72	3.06± 2.16	0.25± 0.35	0.25± 0.36	0.79± 0.34	0.27± 0.38
C-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	2.81± 3.97	0.49± 0.69	1.02± 1.44	0.51± 0.72	0.00± 0.00
Fluoranthene	3.05± 2.87	11.32± 8.91	9.71± 4.32	2.22± 1.07	11.93± 11.84	13.90± 15.79	3.86± 1.68
Pyrene	3.82± 3.95	7.63± 6.52	15.32± 9.36	2.72± 2.46	16.24± 13.63	13.72± 12.43	3.62± 0.59
9-Anthraaldehyde	2.03± 2.87	12.30± 10.99	20.17± 18.39	1.98± 2.80	12.94± 8.97	2.56± 3.62	0.80± 1.13
Retene	0.00± 0.00	0.00± 0.00	0.51± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
benzo(a)fluorene	1.02± 1.44	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00
benzo(b)fluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00
5-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
B-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-MeFl+C-MeFl/Py	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1+3-methylfluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.49± 0.69	0.00± 0.00	2.30± 3.26	0.00± 0.00
4-methylpyrene	0.25± 0.36	0.00± 0.00	2.55± 1.44	0.49± 0.00	1.78± 0.36	2.58± 2.87	0.52± 0.02
C-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00
D-MePy/MeFl	0.00± 0.00	0.00± 0.00	1.79± 2.53	0.00± 0.00	0.00± 0.00	1.28± 1.81	0.00± 0.00
1-methylpyrene	0.00± 0.00	0.00± 0.00	1.53± 2.16	0.00± 0.00	0.51± 0.72	2.30± 3.26	0.27± 0.38
Benzonaphthothiophene	0.00± 0.00	0.00± 0.00	2.55± 3.61	0.00± 0.00	0.00± 0.00	2.45± 2.74	0.00± 0.00
benzo(c)phenanthrene	0.00± 0.00	0.00± 0.00	2.55± 3.61	0.00± 0.00	0.00± 0.00	2.30± 3.26	0.00± 0.00
Benzo(ghi)fluoranthene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00

9-phenylanthracene	0.00± 0.00	0.00± 0.00	1.02± 0.00	0.00± 0.00	0.76± 1.08	0.00± 0.00	0.00± 0.00
6-methylchrysene	0.25± 0.36	0.00± 0.00	0.26± 0.36	0.25± 0.35	0.00± 0.00	0.26± 0.36	0.00± 0.00
Cyclopenta(c,d)pyrene	0.25± 0.36	0.00± 0.00	0.26± 0.36	0.25± 0.35	0.51± 0.72	#DIV/0!	0.00± 0.00
Benz(a)anthracene	0.25± 0.36	0.25± 0.36	0.51± 0.72	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00
Chrysene	1.02± 0.71	1.48± 0.67	0.51± 0.72	0.25± 0.35	0.25± 0.36	#DIV/0!	0.77± 0.34
Benzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00
Benz(a)anthracene-7,12-dione	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	1.92± 2.71	0.00± 0.00
3-methylchrysene	0.00± 0.00	0.00± 0.00	2.04± 2.89	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00
7-methylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7,12-dimethylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)fluoranthene	0.51± 0.72	0.25± 0.36	0.77± 0.36	0.00± 0.00	0.51± 0.00	6.14± 8.68	2.79± 3.19
Benzo(j)fluoranthene	1.78± 2.52	0.75± 1.07	0.77± 0.36	0.00± 0.00	0.00± 0.00	26.69± 21.10	2.80± 2.46
Benzo(k)fluoranthene	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00	1.27± 1.79	4.09± 5.79	0.00± 0.00
Benzo(a)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	1.28± 1.81	0.00± 0.00
BeP	0.76± 1.08	0.00± 0.00	1.28± 1.08	0.25± 0.35	0.25± 0.36	#DIV/0!	0.27± 0.38
BaP	0.51± 0.72	0.00± 0.00	1.53± 0.00	0.00± 0.00	0.51± 0.72	#DIV/0!	0.27± 0.38
Perylene	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00	0.25± 0.36	2.05± 2.89	0.00± 0.00
3-methylcholanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-methylbenzo(a)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00± 0.00	0.00± 0.00	6.63± 9.38	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Indeno[123-cd]fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.51± 0.72	0.00± 0.00
Indeno[123-cd]pyrene	0.51± 0.72	0.00± 0.00	0.51± 0.00	0.00± 0.00	0.51± 0.00	#DIV/0!	0.52± 0.02
Dibenzo(ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00
Dibenzo(ah+ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah)anthracene	0.51± 0.72	0.00± 0.00	0.26± 0.36	0.00± 0.00	0.00± 0.00	2.05± 2.89	0.27± 0.38
Dibenzo(a,j)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.51± 0.72	0.00± 0.00
Benzo(b)chrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.77± 1.09	0.00± 0.00
Picene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.25± 0.35	0.00± 0.00	1.02± 1.45	0.00± 0.00
Benzo(ghi)perylene	0.76± 1.08	0.99± 0.68	0.77± 0.36	0.25± 0.35	0.76± 0.36	#DIV/0!	0.77± 0.34

Anthanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00
Triphenylene	0.25± 0.36	0.50± 0.71	0.00± 0.00	0.00± 0.00	0.00± 0.00	2.05± 2.89	0.52± 0.02
Dibenzo(a,l)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Coronene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	#DIV/0!	0.00± 0.00
Dibenzo(a,e)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.77± 1.09	0.00± 0.00
Dibenzo(a,i)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,h)pyrene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(b,k)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D14: Particle-phase PAH emissions for Vehicle #6

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	13.44± 7.57	6.02± 3.49	22.94± 2.59	8.28± 3.07	14.00± 6.98	6.70± 2.16	50.13± 46.44
quinoline	0.76± 1.07	1.00± 0.70	1.01± 1.42	0.75± 0.34	0.25± 0.36	1.03± 0.00	0.00± 0.00
2-methylnaphthalene	13.72± 3.68	7.03± 3.48	20.42± 1.15	10.04± 3.40	15.26± 5.90	8.51± 3.97	65.09± 63.41
1-methylnaphthalene	7.72± 3.06	3.77± 1.74	11.34± 0.40	4.52± 1.35	7.75± 3.84	4.38± 2.53	32.44± 32.60
Biphenyl	18.95± 6.07	10.81± 3.79	22.44± 1.87	11.81± 3.02	15.75± 8.03	11.87± 0.67	41.78± 17.18
2-methylbiphenyl	78.19± 36.28	45.78± 10.85	74.12± 8.13	43.99± 6.78	42.98± 27.30	48.01± 6.80	48.27± 11.68
2,6+2,7-dimethylnaphthalene	8.73± 2.34	4.01± 2.80	8.07± 0.03	7.03± 2.74	9.01± 1.35	5.67± 2.89	33.32± 25.47
1,3+1,6+1,7dimethylnaphth	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,4+1,5+2,3-dimethylnaphth	15.71± 5.06	8.54± 3.46	17.90± 1.14	8.80± 1.64	11.01± 4.17	11.35± 1.40	34.55± 8.34
Acenaphthylene	13.95± 6.15	8.05± 2.04	14.87± 1.13	7.29± 0.95	7.49± 5.61	8.52± 1.14	9.37± 0.68
1,2-dimethylnaphthalene	9.42± 9.75	1.00± 1.41	8.82± 0.39	6.01± 3.46	5.52± 3.59	1.55± 0.72	17.05± 5.95
1,8-dimethylnaphthalene	3.98± 2.06	1.25± 1.05	4.03± 0.73	3.02± 0.66	2.50± 0.69	2.06± 0.01	4.79± 0.91
Acenaphthene	1.00± 0.02	0.75± 0.35	67.48± 94.01	1.26± 0.34	0.75± 0.36	0.77± 1.09	15.04± 21.27
3-methylbiphenyl	84.20± 34.77	50.31± 12.22	82.69± 7.45	47.76± 8.50	51.49± 29.36	57.03± 2.83	73.00± 37.57
4-methylbiphenyl	42.11± 16.68	25.65± 6.82	41.09± 3.37	24.13± 3.89	25.24± 14.33	28.38± 0.14	41.28± 17.16
1+2ethylnaphthalene	11.95± 5.47	6.79± 2.41	14.37± 0.30	9.28± 3.77	9.25± 3.83	7.48± 0.33	32.21± 5.04
1-ethyl-2-methylnaphthalene	4.20± 5.94	3.25± 4.59	6.81± 1.10	3.48± 4.93	5.25± 1.73	7.48± 1.79	12.19± 17.23
2,3,5+I-trimethylnaphthalene	4.49± 1.35	2.51± 1.39	4.79± 0.34	4.77± 0.99	5.02± 1.46	3.86± 2.54	14.12± 12.29
B-trimethylnaphthalene	3.98± 2.06	7.08± 5.07	2.51± 3.55	4.52± 1.35	4.27± 1.80	2.83± 4.00	24.68± 23.03

A-trimethylnaphthalene	2.49± 0.67	1.51± 0.69	1.26± 1.06	1.75± 1.75	2.26± 0.37	1.55± 0.72	6.68± 5.95
C-trimethylnaphthalene	7.24± 0.95	4.02± 1.38	7.06± 0.69	6.03± 1.33	7.01± 0.05	6.18± 4.35	24.01± 28.37
2-ethyl-1-methylnaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.25± 0.36	0.26± 0.36	0.78± 1.10
E-trimethylnaphthalene	1.50± 0.02	1.51± 0.69	3.02± 0.70	2.01± 0.68	2.50± 0.69	2.06± 1.45	5.96± 8.43
2,4,5-trimethylnaphthalene	6.69± 7.32	1.25± 1.05	1.01± 1.42	3.03± 0.76	1.75± 0.37	1.80± 1.09	6.72± 8.10
F-trimethylnaphthalene	4.76± 1.13	3.52± 1.38	5.04± 1.41	5.02± 1.34	6.02± 1.46	4.89± 3.99	23.59± 33.37
Fluorene	8.26± 1.89	5.78± 3.14	6.30± 3.18	9.03± 4.13	8.28± 2.54	8.24± 7.26	39.02± 47.49
1,4,5-trimethylnaphthalene	0.25± 0.36	0.25± 0.35	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.51± 0.73	0.00± 0.00
J-trimethylnaphthalene	1.24± 1.04	0.50± 0.01	0.00± 0.00	0.25± 0.35	1.01± 1.42	0.77± 1.09	3.37± 4.77
A-Methylfluorene	11.49± 1.24	7.54± 2.76	11.85± 0.40	7.30± 0.24	8.25± 3.12	7.48± 0.33	13.46± 2.97
B-Methylfluorene	1.24± 1.04	0.00± 0.00	4.78± 5.33	0.25± 0.35	1.25± 1.05	0.77± 1.09	1.30± 1.83
1-Methylfluorene	4.01± 1.47	3.26± 1.74	6.55± 0.03	3.27± 0.30	4.26± 0.32	2.84± 0.35	12.00± 6.49
9-fluorenone	3.51± 2.17	2.76± 1.75	3.52± 2.12	1.76± 0.33	2.51± 0.02	4.38± 1.07	8.74± 8.17
Dibenzothiophene	4.25± 0.42	3.01± 1.39	3.53± 0.73	2.27± 0.39	2.51± 0.02	3.87± 0.35	6.68± 5.95
Phenanthrene	21.59± 13.76	17.32± 10.84	17.37± 12.41	21.33± 8.56	18.06± 5.81	21.66± 7.92	70.24± 83.27
Anthracene	9.49± 1.27	5.52± 3.50	22.93± 4.54	6.28± 0.97	11.00± 6.29	3.87± 1.11	23.33± 11.72
Xanthone	1.25± 0.37	0.75± 0.35	1.76± 0.35	0.50± 0.01	2.25± 1.75	0.52± 0.00	1.56± 2.20
1,4-Naphthoquinone	7.58± 10.72	11.11± 3.70	1.01± 1.42	13.36± 1.99	8.31± 11.75	13.67± 1.03	14.08± 19.91
Acenaphthenequinone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.52± 0.73
3-methylphenanthrene	3.26± 1.82	2.51± 2.11	2.52± 1.42	2.26± 1.03	2.76± 1.08	5.16± 0.75	6.43± 6.30
2-methylphenanthrene	4.27± 2.54	3.26± 2.45	2.52± 2.13	3.01± 1.38	3.51± 0.74	6.45± 1.13	8.30± 11.73
Perinaphthenone	206.75± 286.67	2.76± 1.75	139.71± 34.06	2.77± 0.31	37.13± 48.95	6.72± 5.14	198.01± 69.77
2-methylanthracene	3.71± 4.54	0.25± 0.35	0.00± 0.00	0.25± 0.35	0.00± 0.00	0.52± 0.00	0.00± 0.00
4,5-methylenephenanthrene	0.75± 0.36	0.75± 0.35	0.50± 0.71	0.50± 0.01	0.75± 0.36	1.03± 0.00	1.56± 2.20
9-methylphenanthrene	1.26± 1.08	1.50± 1.41	0.50± 0.71	1.26± 0.34	1.00± 0.72	2.32± 0.38	3.63± 5.13
1-methylphenanthrene	1.76± 1.09	1.25± 1.05	0.75± 1.07	1.26± 0.34	1.25± 0.36	2.32± 0.38	2.83± 2.60
Anthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	2.77± 3.92	11.64± 11.37	14.52± 20.53
9-methylanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Anthraquinone	4.48± 2.76	2.51± 1.39	10.84± 1.74	34.37± 45.73	4.24± 3.86	2.84± 0.35	13.48± 19.07
A-dimethylphenanthrene	1.01± 1.43	0.75± 1.06	0.00± 0.00	0.75± 0.34	0.50± 0.71	2.84± 1.11	0.00± 0.00

B-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,7-dimethylphenanthrene	0.00± 0.00	0.50± 0.71	0.00± 0.00	0.25± 0.35	0.25± 0.36	0.52± 0.73	0.00± 0.00
3,6-dimethylphenanthrene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.25± 0.36	0.78± 0.37	0.26± 0.37
D-dimethylphenanthrene	0.51± 0.71	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.25± 0.36	0.52± 0.73	0.00± 0.00
E-dimethylphenanthrene	0.76± 1.07	0.75± 1.06	0.00± 0.00	0.75± 0.34	0.50± 0.71	1.81± 0.37	1.04± 1.47
C-dimethylphenanthrene	30.44± 38.77	1.00± 1.41	0.00± 0.00	0.75± 0.34	0.76± 1.07	1.29± 1.83	2.59± 3.67
Fluoranthene	4.78± 3.96	4.51± 4.22	2.27± 1.77	3.00± 2.09	4.26± 0.39	4.64± 0.02	7.67± 4.56
Pyrene	6.53± 4.34	4.51± 4.22	2.77± 1.06	3.00± 2.09	6.51± 1.37	7.75± 2.23	7.15± 3.82
9-Anthraaldehyde	4.55± 6.43	4.26± 4.58	0.00± 0.00	3.51± 2.08	3.78± 5.34	10.59± 4.07	5.96± 8.43
Retene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
benzo(a)fluorene	0.25± 0.36	0.25± 0.35	0.00± 0.00	0.00± 0.00	0.25± 0.35	0.52± 0.00	0.26± 0.37
benzo(b)fluorene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.37
5-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
B-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-MeFl+C-MeFl/Py	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1+3-methylfluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4-methylpyrene	2.26± 1.80	1.00± 0.70	0.25± 0.36	0.75± 0.34	1.25± 0.36	2.58± 1.47	1.56± 2.20
C-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
D-MePy/MeFl	1.76± 1.79	0.75± 1.06	0.00± 0.00	0.25± 0.35	0.76± 1.07	2.84± 1.84	1.04± 1.47
1-methylpyrene	1.51± 1.44	0.50± 0.71	0.00± 0.00	0.25± 0.35	0.50± 0.71	1.55± 0.74	0.78± 1.10
Benzonaphthothiophene	0.00± 0.00	0.00± 0.00	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.25± 0.35
benzo(c)phenanthrene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.25± 0.36	0.26± 0.37	0.26± 0.37
Benzo(ghi)fluoranthene	1.75± 0.33	0.75± 0.35	4.30± 6.08	0.50± 0.01	0.25± 0.36	1.29± 0.37	1.54± 1.48
9-phenylanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.37
6-methylchrysene	0.50± 0.01	0.00± 0.00	1.01± 1.43	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Cyclopenta(c,d)pyrene	0.25± 0.36	0.25± 0.35	0.00± 0.00	0.00± 0.00	0.25± 0.36	0.78± 0.37	0.52± 0.73
Benz(a)anthracene	0.51± 0.71	0.25± 0.35	0.25± 0.36	0.25± 0.35	0.50± 0.00	0.78± 0.37	1.02± 0.75
Chrysene	1.26± 1.08	1.00± 0.70	0.51± 0.71	1.01± 0.02	0.50± 0.00	0.78± 0.37	1.27± 0.40
Benzanthrone	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.78± 0.37	0.00± 0.00
Benz(a)anthracene-7,12-dione	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

3-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-methylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7,12-dimethylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)fluoranthene	1.26± 1.08	1.00± 0.70	1.01± 0.00	1.01± 0.02	0.50± 0.70	0.26± 0.37	0.78± 1.10
Benzo(j)fluoranthene	0.75± 0.36	0.25± 0.35	1.52± 2.14	0.00± 0.00	0.25± 0.35	0.52± 0.00	0.00± 0.00
Benzo(k)fluoranthene	0.51± 0.71	0.75± 0.35	1.01± 1.42	0.75± 0.34	0.25± 0.35	0.00± 0.00	0.00± 0.00
Benzo(a)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
BeP	2.01± 1.44	1.26± 0.34	3.78± 0.37	1.26± 0.34	1.00± 0.70	0.78± 0.37	1.30± 1.83
BaP	0.51± 0.71	0.25± 0.36	0.00± 0.00	0.25± 0.35	0.25± 0.36	0.52± 0.00	2.07± 2.93
Perylene	0.51± 0.71	0.50± 0.01	0.00± 0.00	0.50± 0.01	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-methylcholanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-methylbenzo(a)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Indeno[123-cd]fluoranthene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.37
Indeno[123-cd]pyrene	0.75± 0.36	0.50± 0.01	0.25± 0.36	0.50± 0.01	0.25± 0.35	0.00± 0.00	0.52± 0.73
Dibenzo(ac)anthracene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah+ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah)anthracene	0.51± 0.71	0.25± 0.36	0.25± 0.36	0.50± 0.01	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,j)anthracene	0.99± 1.40	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)chrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Picene	1.73± 2.45	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.26± 0.36	0.00± 0.00
Benzo(ghi)perylene	1.25± 0.37	1.01± 0.01	0.76± 0.35	1.01± 0.02	0.50± 0.70	0.52± 0.00	1.54± 1.48
Anthanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Triphenylene	0.25± 0.36	0.25± 0.35	0.25± 0.36	0.00± 0.00	0.25± 0.36	0.26± 0.37	0.77± 0.38
Dibenzo(a,l)pyrene	0.25± 0.36	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Coronene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,e)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,i)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,h)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Dibenzo(b,k)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D15: Particle-phase PAH emissions for Vehicle #7

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	3.66± 3.02	16.08± 8.83	11.02± 11.44	3.07± 0.52	46.76± 62.23	5.92± 1.15	3.37± 2.63
quinoline	0.15± 0.22	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.15± 0.22	1.22± 1.73	0.00± 0.00
2-methylnaphthalene	2.90± 1.94	4.20± 2.87	3.72± 2.35	3.84± 0.76	2.45± 0.00	28.26± 31.46	4.45± 3.72
1-methylnaphthalene	1.98± 1.08	2.42± 1.68	2.53± 1.91	2.15± 0.06	1.53± 0.00	7.79± 7.61	2.30± 1.97
Biphenyl	6.87± 4.96	9.43± 1.05	13.41± 13.56	5.35± 0.93	4.29± 0.00	11.25± 3.57	6.27± 2.88
2-methylbiphenyl	14.51± 0.24	17.08± 9.25	17.18± 0.62	13.58± 3.72	13.78± 0.00	18.33± 4.28	18.78± 2.61
2,6+2,7-dimethylnaphthalene	2.59± 1.94	3.22± 1.48	2.83± 2.34	3.37± 0.10	2.45± 0.00	9.45± 7.41	3.99± 3.93
1,3+1,6+1,7dimethylnaphth	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,4+1,5+2,3-dimethylnaphth	3.82± 1.51	5.64± 3.16	4.60± 2.36	4.13± 0.53	3.98± 0.00	16.16± 12.22	5.66± 3.31
Acenaphthylene	2.60± 0.21	3.07± 2.15	2.96± 0.45	2.59± 1.01	3.06± 0.00	3.49± 0.60	3.82± 0.70
1,2-dimethylnaphthalene	0.92± 0.43	1.12± 0.27	2.37± 0.86	1.39± 0.69	98.09± 0.00	43.30± 58.26	1.38± 0.66
1,8-dimethylnaphthalene	0.76± 0.21	0.97± 0.49	0.44± 0.20	1.23± 0.47	48.74± 0.00	13.44± 14.76	1.38± 0.66
Acenaphthene	0.31± 0.43	0.96± 0.04	0.75± 1.06	0.46± 0.23	0.31± 0.00	3.06± 4.33	1.69± 2.39
3-methylbiphenyl	17.10± 2.13	20.80± 11.88	19.71± 2.53	16.04± 3.65	20.52± 0.00	25.64± 0.54	24.30± 8.29
4-methylbiphenyl	8.70± 1.50	10.96± 5.85	10.23± 1.16	8.55± 1.92	10.11± 0.00	14.42± 0.39	12.54± 4.47
1+2ethylnaphthalene	2.75± 0.86	3.54± 1.49	4.61± 3.19	3.37± 0.34	2.76± 0.00	7.46± 4.60	3.98± 1.78
1-ethyl-2-methylnaphthalene	4.89± 0.86	5.56± 0.90	2.06± 2.91	2.25± 3.18	4.59± 0.00	16.23± 22.95	3.08± 4.35
2,3,5+I-trimethylnaphthalene	1.83± 1.29	2.26± 1.44	1.93± 1.49	2.15± 0.50	2.14± 0.00	3.50± 2.40	2.46± 2.62
B-trimethylnaphthalene	1.83± 1.29	2.10± 1.21	1.34± 1.90	2.00± 0.27	1.53± 0.00	0.00± 0.00	2.62± 3.70
A-trimethylnaphthalene	0.76± 0.21	0.64± 0.03	0.74± 0.64	0.61± 0.02	1.23± 0.00	2.75± 3.47	0.92± 1.31
C-trimethylnaphthalene	2.44± 1.72	2.73± 1.24	2.97± 2.13	3.07± 0.09	2.76± 0.00	1.35± 1.91	3.99± 3.93
2-ethyl-1-methylnaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.16± 0.22	0.00± 0.00	0.15± 0.21	0.00± 0.00
E-trimethylnaphthalene	0.76± 0.65	1.13± 0.72	1.04± 1.06	0.92± 0.03	0.92± 0.00	0.00± 0.00	1.23± 1.74
2,4,5-trimethylnaphthalene	0.61± 0.43	0.82± 1.16	0.73± 1.04	0.92± 0.03	0.92± 0.00	0.00± 0.00	1.38± 1.53
F-trimethylnaphthalene	2.29± 1.94	2.42± 1.68	1.78± 1.28	2.45± 0.07	2.76± 0.00	3.21± 3.26	3.54± 4.58
Fluorene	4.27± 3.88	5.94± 2.27	6.24± 3.84	4.44± 0.09	4.29± 0.00	15.59± 19.08	6.76± 8.28

1,4,5-trimethylnaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.61± 0.00	0.00± 0.00	0.31± 0.44
J-trimethylnaphthalene	0.46± 0.65	0.00± 0.00	0.15± 0.21	0.47± 0.66	0.31± 0.00	9.18± 12.99	0.62± 0.87
A-Methylfluorene	4.27± 1.29	7.59± 3.30	16.58± 1.07	3.82± 0.97	3.68± 0.00	1.65± 2.34	3.82± 1.56
B-Methylfluorene	0.00± 0.00	0.16± 0.23	0.00± 0.00	0.00± 0.00	0.31± 0.00	0.00± 0.00	0.31± 0.44
1-Methylfluorene	2.29± 1.94	12.49± 13.03	44.09± 7.04	2.59± 1.01	1.53± 0.00	0.90± 1.28	2.61± 2.84
9-fluorenone	2.29± 1.51	13.80± 11.62	41.37± 9.48	2.15± 0.06	3.37± 0.00	0.45± 0.64	1.84± 1.75
Dibenzothiophene	1.37± 0.65	1.46± 1.19	1.18± 0.01	1.37± 0.61	1.84± 0.00	0.30± 0.43	1.69± 1.53
Phenanthrene	9.16± 7.76	10.52± 7.86	9.37± 6.18	9.46± 2.76	8.58± 0.00	33.65± 42.90	15.84± 19.83
Anthracene	3.81± 3.67	3.37± 1.26	5.20± 3.62	3.65± 1.63	1.23± 0.00	6.05± 2.93	3.06± 1.33
Xanthone	2.75± 3.45	0.65± 0.48	0.59± 0.43	0.15± 0.21	0.31± 0.00	0.00± 0.00	0.46± 0.22
1,4-Naphthoquinone	12.67± 3.65	8.71± 3.03	4.85± 6.86	7.53± 1.74	4.44± 6.28	0.00± 0.00	3.69± 5.22
Acenaphthenequinone	0.00± 0.00	0.00± 0.00	0.15± 0.21	0.00± 0.00	0.15± 0.22	0.00± 0.00	0.00± 0.00
3-methylphenanthrene	1.07± 1.08	1.46± 1.19	0.89± 0.43	1.22± 0.40	1.23± 0.00	0.00± 0.00	1.84± 1.75
2-methylphenanthrene	1.53± 1.29	2.87± 0.11	3.71± 1.93	1.38± 0.18	1.23± 0.00	0.00± 0.00	2.30± 2.40
Perinaphthenone	10.98± 14.24	18.92± 18.41	51.26± 3.52	1.53± 0.39	0.92± 0.00	171.52± 109.85	2.14± 1.32
2-methylanthracene	0.31± 0.43	1.15± 1.62	0.45± 0.63	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4,5-methylenephenanthrene	0.46± 0.22	0.48± 0.24	0.00± 0.00	0.31± 0.01	0.31± 0.00	0.00± 0.00	0.46± 0.65
9-methylphenanthrene	0.76± 0.65	1.26± 0.85	0.73± 1.04	0.61± 0.02	0.61± 0.00	0.00± 0.00	0.92± 1.31
1-methylphenanthrene	0.46± 0.22	0.49± 0.70	0.89± 0.43	0.61± 0.42	0.61± 0.00	0.00± 0.00	0.77± 1.09
Anthrone	10.07± 14.24	18.37± 25.98	0.00± 0.00	1.41± 1.99	0.00± 0.00	0.00± 0.00	0.00± 0.00
9-methylanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Anthraquinone	1.07± 0.21	6.00± 4.97	1.76± 2.49	1.53± 0.39	3.37± 0.00	22.48± 28.39	8.93± 10.02
A-dimethylphenanthrene	0.76± 0.65	5.12± 7.24	0.00± 0.00	0.31± 0.01	0.00± 0.00	0.00± 0.00	0.00± 0.00
B-dimethylphenanthrene	0.46± 0.65	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,7-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3,6-dimethylphenanthrene	0.61± 0.86	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
D-dimethylphenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
E-dimethylphenanthrene	0.00± 0.00	0.33± 0.46	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.15± 0.22
C-dimethylphenanthrene	2.44± 3.45	5.61± 6.54	6.32± 8.93	0.16± 0.22	0.00± 0.00	0.00± 0.00	0.77± 0.66
Fluoranthene	1.07± 0.65	1.94± 1.43	1.19± 0.85	1.07± 0.19	0.92± 0.00	0.30± 0.43	1.69± 1.53

Pyrene	1.07± 0.65	1.94± 1.43	0.89± 0.43	0.76± 0.19	0.61± 0.00	1.22± 0.87	1.53± 0.88
9-Anthraaldehyde	0.15± 0.22	1.64± 2.32	0.00± 0.00	1.22± 0.40	1.23± 0.00	0.00± 0.00	0.92± 1.31
Retene	0.00± 0.00	0.16± 0.23	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
benzo(a)fluorene	1.68± 2.37	0.33± 0.46	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.15± 0.22
benzo(b)fluorene	2.14± 3.02	0.00± 0.00	0.44± 0.20	0.00± 0.00	0.00± 0.00	0.31± 0.43	0.00± 0.00
5-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	3.21± 4.55	0.00± 0.00
B-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-MeFl+C-MeFl/Py	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1+3-methylfluoranthene	0.00± 0.00	0.78± 1.10	2.52± 0.66	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4-methylpyrene	0.61± 0.86	0.47± 0.21	1.19± 0.43	0.31± 0.01	0.00± 0.00	0.00± 0.00	0.15± 0.22
C-MePy/MeFl	0.00± 0.00	0.31± 0.44	0.89± 0.01	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
D-MePy/MeFl	0.46± 0.65	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-methylpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzonaphthothiophene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
benzo(c)phenanthrene	0.00± 0.00	1.09± 1.53	3.41± 0.25	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(ghi)fluoranthene	0.15± 0.22	0.63± 0.43	1.33± 0.22	0.15± 0.21	0.00± 0.00	0.00± 0.00	0.31± 0.44
9-phenylanthracene	0.00± 0.00	0.62± 0.88	1.93± 0.23	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6-methylchrysene	0.15± 0.22	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Cyclopenta(c,d)pyrene	0.00± 0.00	0.94± 0.86	2.37± 0.45	0.00± 0.00	1.38± 1.94	0.00± 0.00	0.15± 0.22
Benz(a)anthracene	1.22± 1.29	0.00± 0.00	0.00± 0.00	0.00± 0.00	1.68± 2.38	0.00± 0.00	0.00± 0.00
Chrysene	0.76± 1.08	0.79± 0.19	1.19± 1.69	0.30± 0.42	2.90± 4.11	3.98± 5.63	0.61± 0.01
Benzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benz(a)anthracene-7,12-dione	1.37± 1.51	2.48± 3.51	2.50± 3.53	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	12.40± 17.53	0.00± 0.00
7-methylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7,12-dimethylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)fluoranthene	0.46± 0.22	0.48± 0.24	0.59± 0.43	0.30± 0.42	1.53± 2.16	0.00± 0.00	0.76± 0.23
Benzo(j)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.92± 1.30	0.00± 0.00	0.15± 0.21
Benzo(k)fluoranthene	0.15± 0.22	0.33± 0.46	0.15± 0.21	0.30± 0.42	1.68± 2.38	0.00± 0.00	0.46± 0.22

Benzo(a)fluoranthene	0.00± 0.00	0.00± 0.00	0.15± 0.21	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
BeP	0.31± 0.43	0.65± 0.48	0.59± 0.43	0.30± 0.42	2.75± 3.89	0.00± 0.00	1.07± 0.23
BaP	0.31± 0.43	0.32± 0.01	0.45± 0.21	0.15± 0.21	1.53± 2.16	0.00± 0.00	0.31± 0.00
Perylene	0.15± 0.22	0.16± 0.23	0.15± 0.21	0.15± 0.21	1.83± 2.59	0.00± 0.00	0.31± 0.00
3-methylcholanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-methylbenzo(a)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Indeno[123-cd]fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.92± 1.30	0.00± 0.00	0.00± 0.00
Indeno[123-cd]pyrene	0.15± 0.22	0.33± 0.46	0.30± 0.42	0.30± 0.42	2.29± 3.24	0.00± 0.00	0.61± 0.01
Dibenzo(ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah+ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah)anthracene	0.31± 0.43	0.33± 0.46	0.30± 0.42	0.30± 0.42	1.68± 2.38	0.00± 0.00	0.31± 0.00
Dibenzo(a,j)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)chrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Picene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	2.26± 3.19	0.00± 0.00
Benzo(ghi)perylene	0.61± 0.43	0.81± 0.71	0.75± 1.06	0.45± 0.64	2.90± 4.11	0.15± 0.21	1.22± 0.02
Anthanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Triphenylene	0.00± 0.00	0.47± 0.21	8.00± 0.51	0.15± 0.21	1.83± 2.59	0.00± 0.00	0.15± 0.22
Dibenzo(a,l)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Coronene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,e)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,i)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,h)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(b,k)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D16: Particle-phase PAH emissions for Vehicle #8

Component (ng/mile)	Fed ULSD	CARB ULSD	Fed/SME-20	Fed/AFME-20	Fed/WCO-20	Fed/HVO-20	CARB/WCO-20
naphthalene	75.17± 10.81	112.07± 15.87	84.91± 27.73	57.73± 26.85	3.60± 0.93	50.19± 34.70	5.39± 2.92

quinoline	3.35± 2.91	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.64± 0.30	0.00± 0.00	0.21± 0.29
2-methylnaphthalene	18.13± 1.38	17.75± 2.61	15.08± 5.81	12.18± 5.18	3.81± 0.63	20.54± 3.05	5.80± 2.92
1-methylnaphthalene	9.50± 2.35	11.83± 3.42	12.06± 3.14	7.14± 10.10	1.91± 0.91	12.27± 2.87	3.11± 1.46
Biphenyl	17.24± 3.84	15.72± 8.28	12.12± 5.06	9.85± 3.81	6.14± 0.95	16.63± 3.12	8.29± 0.58
2-methylbiphenyl	35.70± 20.92	14.21± 15.47	16.77± 15.17	29.36± 0.77	20.72± 2.81	8.29± 4.71	26.33± 2.09
2,6+2,7-dimethylnaphthalene	2.28± 0.36	5.74± 1.45	4.71± 1.30	1.79± 1.46	3.82± 1.83	2.56± 0.66	4.77± 2.05
1,3+1,6+1,7dimethylnaphth	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,4+1,5+2,3-dimethylnaphth	1.51± 1.44	3.36± 2.43	5.17± 3.07	2.94± 2.32	4.87± 0.94	2.55± 2.56	7.26± 0.87
Acenaphthylene	0.37± 0.64	6.98± 6.15	3.13± 4.13	0.00± 0.00	4.02± 0.26	0.00± 0.00	5.18± 0.30
1,2-dimethylnaphthalene	0.01± 0.02	0.00± 0.00	0.00± 0.00	0.94± 1.33	2.54± 0.62	0.00± 0.00	2.49± 1.17
1,8-dimethylnaphthalene	2.48± 4.30	11.05± 19.13	3.94± 3.42	0.00± 0.00	1.48± 0.29	6.40± 0.46	1.66± 0.58
Acenaphthene	2.07± 3.59	4.10± 6.39	4.38± 7.59	6.64± 9.13	0.42± 0.00	0.00± 0.00	0.62± 0.29
3-methylbiphenyl	34.33± 15.42	20.91± 16.57	25.91± 15.18	28.16± 1.96	23.90± 0.69	19.08± 6.44	34.21± 1.51
4-methylbiphenyl	14.03± 7.92	7.90± 7.86	11.27± 6.47	11.47± 0.03	12.90± 0.19	9.64± 1.00	17.42± 0.61
1+2ethylnaphthalene	0.00± 0.00	0.00± 0.00	0.97± 1.69	0.00± 0.00	3.81± 0.03	1.06± 1.84	5.18± 0.87
1-ethyl-2-methylnaphthalene	5.45± 1.65	6.48± 0.83	4.10± 3.55	3.92± 4.22	0.00± 0.00	1.01± 1.75	3.32± 4.70
2,3,5+I-trimethylnaphthalene	1.17± 1.44	2.47± 0.84	1.52± 1.39	1.58± 0.02	2.12± 0.62	1.03± 0.90	3.73± 1.75
B-trimethylnaphthalene	10.72± 9.26	0.76± 0.20	0.51± 0.44	9.36± 13.24	1.91± 0.91	0.46± 0.47	3.52± 0.87
A-trimethylnaphthalene	0.00± 0.00	0.74± 1.28	0.00± 0.00	0.00± 0.00	0.85± 0.61	0.00± 0.00	1.45± 0.29
C-trimethylnaphthalene	4.87± 1.96	8.77± 3.73	12.58± 2.34	0.00± 0.00	2.75± 0.92	10.53± 0.57	4.97± 1.75
2-ethyl-1-methylnaphthalene	1.30± 2.26	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.21± 0.30	0.21± 0.37	0.21± 0.29
E-trimethylnaphthalene	7.72± 6.74	2.05± 1.78	1.98± 1.24	3.66± 0.36	0.64± 0.30	2.67± 1.36	1.45± 0.88
2,4,5-trimethylnaphthalene	10.36± 7.94	0.00± 0.00	0.00± 0.00	23.27± 0.20	0.42± 0.59	0.00± 0.00	2.70± 0.88
F-trimethylnaphthalene	0.70± 1.20	0.27± 0.46	0.00± 0.00	8.63± 12.17	2.33± 0.92	0.00± 0.00	4.56± 1.75
Fluorene	1.34± 0.84	1.08± 0.98	1.51± 1.37	0.73± 0.79	3.82± 1.83	1.60± 1.43	8.29± 2.33
1,4,5-trimethylnaphthalene	4.43± 1.37	4.16± 0.86	5.50± 1.57	3.30± 0.67	0.00± 0.00	3.68± 1.46	0.00± 0.00
J-trimethylnaphthalene	9.46± 6.24	0.00± 0.00	0.00± 0.00	25.66± 0.92	0.42± 0.00	0.00± 0.00	0.62± 0.29
A-Methylfluorene	11.98± 3.93	6.66± 1.86	8.19± 2.32	11.94± 3.86	4.87± 0.34	6.97± 1.93	7.46± 1.16
B-Methylfluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-Methylfluorene	0.00± 0.00	0.00± 0.00	1.23± 1.59	0.00± 0.00	3.18± 1.52	0.48± 0.83	7.46± 2.92

9-fluorenone	3.93± 1.79	5.35± 2.61	5.43± 1.69	15.96± 12.33	4.45± 2.13	7.53± 1.77	10.57± 5.56
Dibenzothiophene	3.27± 1.10	0.93± 0.50	2.10± 0.61	3.82± 0.87	1.27± 0.01	1.70± 0.23	2.28± 0.29
Phenanthrene	2.51± 2.24	5.86± 7.49	1.18± 1.32	2.36± 1.22	6.57± 2.75	6.99± 7.93	15.34± 4.67
Anthracene	0.76± 1.32	0.00± 0.00	0.00± 0.00	2.94± 4.16	2.75± 0.32	0.00± 0.00	2.28± 2.05
Xanthone	10.81± 0.33	9.48± 1.64	14.34± 1.80	10.73± 1.60	0.21± 0.30	11.36± 4.10	0.41± 0.00
1,4-Naphthoquinone	34.82± 32.68	9.09± 15.75	20.68± 29.38	15.05± 21.29	12.27± 0.11	44.44± 29.39	13.89± 2.03
Acenaphthenequinone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	7.04± 9.96
3-methylphenanthrene	11.13± 2.77	10.00± 10.21	13.80± 5.36	20.07± 8.86	0.85± 0.01	1.13± 1.95	1.66± 0.00
2-methylphenanthrene	2.61± 2.29	0.82± 1.42	0.00± 0.00	10.14± 5.78	1.48± 0.31	2.94± 5.09	2.69± 0.88
Perinaphthenone	132.10± 48.83	47.23± 64.69	49.52± 46.13	75.49± 42.37	8.27± 3.96	41.98± 36.80	14.09± 4.67
2-methylanthracene	1.42± 1.27	0.84± 0.29	1.49± 0.96	2.95± 4.17	0.00± 0.00	1.71± 0.85	0.83± 0.00
4,5-methylenephenanthrene	2.75± 0.22	3.06± 0.96	2.16± 0.30	2.90± 0.52	0.21± 0.30	1.96± 0.79	0.41± 0.00
9-methylphenanthrene	1.65± 1.73	0.70± 0.94	0.00± 0.00	12.09± 9.98	0.42± 0.00	0.79± 1.14	1.45± 0.29
1-methylphenanthrene	1.14± 0.31	2.74± 2.52	2.53± 0.68	0.63± 0.90	0.64± 0.30	2.49± 1.96	1.04± 0.29
Anthrone	103.56± 91.48	59.05± 102.28	17.22± 29.83	368.99± 215.18	0.00± 0.00	25.19± 43.64	6.23± 8.80
9-methylanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Anthraquinone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.64± 0.30	0.96± 1.62	2.07± 1.17
A-dimethylphenanthrene	0.00± 0.00	0.18± 0.31	0.18± 0.31	0.00± 0.00	0.00± 0.00	0.36± 0.63	2.69± 0.29
B-dimethylphenanthrene	0.43± 0.74	0.00± 0.00	0.20± 0.34	0.66± 0.94	0.00± 0.00	0.59± 1.02	0.00± 0.00
1,7-dimethylphenanthrene	0.25± 0.43	1.12± 0.09	0.17± 0.30	1.24± 1.75	0.00± 0.00	0.00± 0.00	0.21± 0.29
3,6-dimethylphenanthrene	0.16± 0.27	0.38± 0.35	0.00± 0.00	0.36± 0.51	0.00± 0.00	0.64± 1.11	0.00± 0.00
D-dimethylphenanthrene	0.44± 0.42	0.28± 0.49	0.23± 0.41	1.90± 2.69	0.00± 0.00	0.69± 1.19	0.00± 0.00
E-dimethylphenanthrene	1.08± 0.98	0.70± 0.78	0.00± 0.00	5.00± 3.32	0.00± 0.00	0.14± 0.24	0.21± 0.29
C-dimethylphenanthrene	0.00± 0.00	2.64± 2.86	0.00± 0.00	0.68± 0.96	1.26± 1.78	2.27± 3.93	4.15± 5.87
Fluoranthene	7.10± 3.99	15.98± 23.33	6.36± 6.14	13.75± 6.32	0.85± 0.01	26.46± 15.34	1.45± 0.29
Pyrene	13.12± 5.34	22.16± 26.91	13.83± 9.74	14.58± 6.04	1.27± 0.01	42.83± 19.28	1.24± 0.00
9-Anthraaldehyde	1.24± 2.15	4.53± 6.60	5.13± 4.52	8.67± 9.06	0.00± 0.00	11.39± 10.94	0.62± 0.88
Retene	0.94± 0.29	0.83± 0.55	1.21± 0.56	1.28± 0.60	0.00± 0.00	1.39± 0.08	0.00± 0.00
benzo(a)fluorene	0.59± 1.03	0.54± 0.94	0.85± 1.48	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
benzo(b)fluorene	1.54± 1.35	1.09± 0.39	0.72± 1.25	0.00± 0.00	0.00± 0.00	1.09± 0.97	0.00± 0.00

5-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
B-MePy/MeFl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-MeFl+C-MeFl/Py	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1+3-methylfluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4-methylpyrene	7.09± 1.38	6.30± 5.21	10.34± 2.81	6.97± 0.55	0.42± 0.00	16.27± 10.13	0.41± 0.00
C-MePy/MeFl	2.82± 4.88	2.64± 4.58	0.92± 1.60	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
D-MePy/MeFl	3.32± 3.45	3.80± 4.33	5.16± 2.94	3.74± 0.11	0.21± 0.30	10.44± 7.76	0.00± 0.00
1-methylpyrene	2.82± 0.82	3.58± 3.43	4.10± 2.72	2.96± 0.34	0.42± 0.00	7.20± 4.12	0.00± 0.00
Benzonaphthothiophene	1.31± 0.53	0.75± 0.97	0.53± 0.92	0.68± 0.96	0.00± 0.00	1.81± 0.32	0.00± 0.00
benzo(c)phenanthrene	0.52± 0.54	1.05± 0.65	0.50± 0.86	0.79± 0.43	0.21± 0.30	1.16± 0.18	0.41± 0.59
Benzo(ghi)fluoranthene	5.44± 4.75	9.29± 8.12	7.10± 6.66	5.12± 1.77	0.42± 0.00	11.86± 2.95	0.62± 0.29
9-phenylanthracene	4.20± 2.94	3.36± 0.74	5.51± 4.91	1.35± 1.91	0.00± 0.00	10.48± 0.98	0.21± 0.29
6-methylchrysene	0.42± 0.73	0.37± 0.63	0.00± 0.00	0.37± 0.53	0.00± 0.00	0.31± 0.53	0.00± 0.00
Cyclopenta(c,d)pyrene	1.53± 1.78	3.21± 4.28	2.35± 2.75	1.09± 0.65	0.42± 0.00	2.98± 3.47	0.41± 0.00
Benz(a)anthracene	0.75± 1.10	0.57± 0.62	1.64± 2.06	0.27± 0.24	0.00± 0.00	1.39± 0.34	0.00± 0.00
Chrysene	0.60± 0.68	1.35± 0.97	1.87± 2.85	2.66± 1.48	0.21± 0.30	1.68± 0.39	0.41± 0.00
Benzanthrone	7.66± 3.12	4.54± 2.24	3.46± 3.91	11.02± 0.17	0.00± 0.00	3.82± 2.91	0.00± 0.00
Benz(a)anthracene-7,12-dione	0.00± 0.00	0.93± 1.61	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	1.66± 0.00
3-methylchrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.76± 1.31	0.00± 0.00
7-methylbenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7,12-dimethylbenz(a)anthracene	1.16± 0.49	2.50± 0.87	3.30± 0.79	3.56± 2.42	0.00± 0.00	2.53± 2.22	0.00± 0.00
Benzo(b)fluoranthene	1.11± 1.40	1.67± 1.62	2.32± 3.42	1.01± 0.45	0.00± 0.00	1.19± 1.67	0.21± 0.29
Benzo(j)fluoranthene	0.53± 0.76	0.78± 0.71	1.43± 1.90	0.64± 0.47	0.00± 0.00	0.79± 0.86	0.00± 0.00
Benzo(k)fluoranthene	0.51± 0.88	0.68± 1.18	1.32± 2.00	0.48± 0.68	0.00± 0.00	0.69± 1.19	0.00± 0.00
Benzo(a)fluoranthene	0.00± 0.00	0.00± 0.00	0.32± 0.55	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
BeP	1.51± 1.09	2.10± 1.72	2.34± 2.10	1.14± 0.21	0.21± 0.30	2.05± 1.25	0.21± 0.29
BaP	1.24± 1.18	1.12± 1.54	1.90± 2.56	0.65± 0.11	0.00± 0.00	1.20± 1.10	0.00± 0.00
Perylene	0.00± 0.00	6.45± 11.18	0.56± 0.96	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-methylcholanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

7-methylbenzo(a)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00± 0.00	0.00± 0.00	0.02± 0.03	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Indeno[123-cd]fluoranthene	0.55± 0.50	0.74± 0.67	0.26± 0.44	1.15± 0.18	0.00± 0.00	0.30± 0.26	0.00± 0.00
Indeno[123-cd]pyrene	0.71± 0.88	0.62± 1.08	1.35± 1.71	0.74± 0.37	0.00± 0.00	0.61± 0.84	0.21± 0.29
Dibenzo(ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah+ac)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(ah)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.21± 0.29
Dibenzo(a,j)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Benzo(b)chrysene	0.31± 0.54	0.70± 1.22	1.27± 0.13	2.03± 0.62	0.00± 0.00	0.69± 0.25	0.00± 0.00
Picene	1.10± 0.95	0.75± 1.30	0.00± 0.00	3.00± 1.19	0.21± 0.30	0.00± 0.00	0.42± 0.59
Benzo(ghi)perylene	1.32± 2.29	3.20± 4.96	3.10± 5.22	0.86± 0.72	0.00± 0.00	2.65± 4.15	0.21± 0.29
Anthanthrene	0.34± 0.59	0.55± 0.94	0.87± 1.23	0.33± 0.46	0.00± 0.00	0.60± 0.85	0.00± 0.00
Triphenylene	2.34± 0.51	3.01± 0.95	2.61± 0.96	2.45± 0.81	0.64± 0.30	2.54± 0.32	1.24± 0.58
Dibenzo(a,l)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Coronene	0.42± 0.73	1.66± 1.92	1.51± 2.61	0.16± 0.23	0.00± 0.00	1.33± 1.87	0.00± 0.00
Dibenzo(a,e)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,i)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(a,h)pyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
Dibenzo(b,k)fluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D17: Gas-phase nitro-PAH emissions for Vehicle #1

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	30.32± 7.21	0.00± 0.00	13.72± 6.63	14.49± 1.46	16.64± 5.85	19.22± 0.00	17.92± 25.34
1-methyl-5-nitronaphthalene	0.00± 0.00	0.05± 0.08	0.75± 0.52	0.00± 0.00	0.00± 0.00	13.64± 0.00	0.00± 0.00
2-nitronaphthalene	0.00± 0.00	3.83± 0.06	1.62± 0.42	0.49± 0.64	0.29± 0.21	7.59± 6.68	0.86± 0.68
2-nitrobiphenyl	0.16± 0.05	0.57± 0.41	0.30± 0.31	0.23± 0.04	0.13± 0.17	0.31± 0.00	0.34± 0.37
2-methyl-4-nitronaphthalene	0.00± 0.00	0.26± 0.10	0.16± 0.23	0.02± 0.02	0.03± 0.04	9.90± 7.31	0.00± 0.00
1-methyl-4-nitronaphthalene	0.00± 0.00	0.61± 0.06	0.48± 0.18	0.09± 0.12	0.00± 0.00	7.89± 7.73	0.28± 0.40
1-methyl-6-nitronaphthalene	0.00± 0.00	5.40± 1.26	1.71± 0.43	1.17± 1.65	2.11± 0.82	0.00± 0.00	3.67± 2.25
3-nitrobiphenyl	0.05± 0.01	0.16± 0.02	0.15± 0.05	0.20± 0.09	0.11± 0.02	0.10± 0.02	0.10± 0.08

4-nitrobiphenyl	0.00± 0.00	0.64± 0.90	0.13± 0.19	0.41± 0.58	0.00± 0.00	0.14± 0.20	0.28± 0.40
1,3-dinitronaphthalene	0.02± 0.02	1.57± 1.31	0.90± 1.24	0.21± 0.30	0.06± 0.08	0.78± 0.14	0.73± 0.63
1,5-dinitronaphthalene	0.06± 0.03	0.00± 0.00	0.15± 0.10	0.13± 0.03	0.54± 0.42	0.08± 0.12	0.00± 0.00
5-nitroacenaphthene	0.04± 0.06	0.00± 0.00	0.00± 0.00	0.04± 0.06	0.00± 0.00	0.19± 0.27	0.00± 0.00
2-nitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9-nitroanthracene	0.00± 0.00	0.05± 0.07	0.00± 0.00	0.24± 0.20	0.29± 0.11	0.35± 0.06	0.33± 0.47
9-nitrophenanthrene	0.00± 0.00	0.15± 0.21	0.54± 0.54	0.09± 0.04	0.15± 0.21	0.71± 0.26	0.28± 0.40
1,8-dinitronaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrophenanthrene	4.65± 1.19	9.46± 0.12	12.34± 11.89	10.91± 1.49	23.39± 3.59	8.33± 6.73	8.04± 0.82
2-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.18± 0.25	0.00± 0.00	0.00± 0.00	0.05± 0.07
2-nitroanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.07± 0.10
4-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitropyrene	0.00± 0.00	0.01± 0.01	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluoren-9-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-nitrobenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6-nitrochrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D18: Gas-phase nitro-PAH emissions for Vehicle #2

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	3.28± 4.63	3.12± 4.41	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-methyl-5-nitronaphthalene	2.46± 0.53	0.12± 0.17	1.22± 0.29	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitronaphthalene	1.19± 0.07	1.12± 0.25	5.45± 1.22	0.47± 0.27	0.99± 0.51	1.39± 0.19	9.51± 0.00
2-nitrobiphenyl	0.27± 0.37	0.44± 0.13	0.22± 0.11	0.63± 0.15	0.53± 0.08	0.49± 0.21	0.95± 0.25
2-methyl-4-nitronaphthalene	0.25± 0.18	0.20± 0.29	1.00± 0.04	0.04± 0.06	0.07± 0.09	0.00± 0.00	0.00± 0.00
1-methyl-4-nitronaphthalene	0.49± 0.31	0.38± 0.54	1.36± 0.08	0.57± 0.05	0.83± 0.08	0.66± 0.07	0.00± 0.00
1-methyl-6-nitronaphthalene	3.32± 3.08	4.09± 1.66	9.98± 5.83	4.39± 3.11	3.09± 4.37	1.49± 0.58	4.89± 1.92
3-nitrobiphenyl	0.27± 0.09	0.22± 0.09	0.50± 0.15	0.13± 0.01	0.33± 0.20	0.20± 0.10	0.42± 0.15
4-nitrobiphenyl	0.54± 0.54	0.34± 0.43	0.32± 0.46	0.18± 0.00	0.13± 0.19	0.12± 0.17	0.00± 0.00
1,3-dinitronaphthalene	0.39± 0.55	0.68± 0.96	0.15± 0.21	0.26± 0.24	0.57± 0.81	0.04± 0.06	0.00± 0.00
1,5-dinitronaphthalene	0.07± 0.10	0.00± 0.00	0.03± 0.04	0.04± 0.05	0.05± 0.06	0.00± 0.00	0.18± 0.18
5-nitroacenaphthene	0.60± 0.12	0.00± 0.00	0.30± 0.22	0.11± 0.16	0.00± 0.00	0.00± 0.00	0.11± 0.16
2-nitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.03± 0.04	0.00± 0.00	0.00± 0.00
4-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9-nitroanthracene	0.97± 0.94	0.47± 0.67	0.26± 0.04	0.27± 0.38	0.35± 0.49	0.33± 0.29	0.81± 0.12
9-nitrophenanthrene	0.58± 0.10	0.69± 0.29	1.07± 0.37	0.31± 0.44	0.65± 0.39	0.85± 0.01	0.38± 0.23
1,8-dinitronaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.10± 0.13	0.00± 0.00	0.00± 0.00
3-nitrophenanthrene	6.15± 0.71	3.59± 5.08	11.69± 3.33	3.45± 0.85	11.50± 9.50	20.91± 17.34	14.50± 7.62
2-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.40± 0.57	0.02± 0.03	0.00± 0.00
2-nitroanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluoren-9-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-nitrobenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6-nitrochrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D19: Gas-phase nitro-PAH emissions for Vehicle #3

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	14.19± 11.97	0.00± 0.00	0.00± 0.00	17.33± 2.33	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-methyl-5-nitronaphthalene	0.47± 0.44	0.14± 0.02	0.54± 0.25	1.24± 0.73	0.45± 0.18	0.22± 0.01	0.73± 0.07
2-nitronaphthalene	1.83± 2.59	1.23± 0.30	2.81± 0.38	0.51± 0.30	3.16± 0.06	1.99± 0.06	2.91± 0.38
2-nitrobiphenyl	0.30± 0.22	0.43± 0.09	0.64± 0.01	0.27± 0.11	0.70± 0.09	0.55± 0.05	0.88± 0.22
2-methyl-4-nitronaphthalene	0.04± 0.05	0.28± 0.01	0.62± 0.14	0.00± 0.00	0.52± 0.09	0.63± 0.04	0.69± 0.12
1-methyl-4-nitronaphthalene	0.07± 0.10	0.25± 0.00	0.93± 0.16	0.14± 0.20	0.71± 0.11	0.55± 0.02	0.92± 0.22
1-methyl-6-nitronaphthalene	0.53± 0.74	3.73± 1.75	1.35± 0.07	0.54± 0.76	0.05± 0.07	1.57± 2.21	2.87± 0.97
3-nitrobiphenyl	0.08± 0.08	0.09± 0.08	0.07± 0.01	0.00± 0.00	0.13± 0.05	0.07± 0.01	0.10± 0.02
4-nitrobiphenyl	0.00± 0.00	0.17± 0.14	0.00± 0.00	0.00± 0.00	0.03± 0.04	0.00± 0.00	0.00± 0.00
1,3-dinitronaphthalene	0.00± 0.00	0.00± 0.00	0.15± 0.05	0.00± 0.00	0.05± 0.08	0.32± 0.07	0.13± 0.08
1,5-dinitronaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.02± 0.02	0.01± 0.01
5-nitroacenaphthene	0.00± 0.00	0.00± 0.00	0.04± 0.02	0.00± 0.00	0.05± 0.05	0.25± 0.35	0.00± 0.00
2-nitrofluorene	0.00± 0.00	0.00± 0.00	0.08± 0.05	0.00± 0.00	0.04± 0.01	0.11± 0.04	0.07± 0.10
4-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.08± 0.12	0.00± 0.00	0.18± 0.25	0.34± 0.04	0.21± 0.29
9-nitroanthracene	0.02± 0.03	1.40± 1.98	0.00± 0.00	0.00± 0.00	0.42± 0.31	0.63± 0.89	1.02± 1.44
9-nitrophenanthrene	0.00± 0.00	0.06± 0.08	1.62± 1.93	0.00± 0.00	0.93± 0.39	1.64± 0.43	3.35± 1.45
1,8-dinitronaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.01± 0.01	0.00± 0.00
3-nitrophenanthrene	0.81± 0.57	2.73± 3.75	0.60± 0.85	1.36± 1.04	1.66± 2.35	0.35± 0.49	0.00± 0.00
2-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitroanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

2-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.18± 0.09	0.16± 0.23	0.05± 0.07
3-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.12± 0.17	0.00± 0.00	0.00± 0.00
2-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluoren-9-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-nitrobenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6-nitrochrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D20: Gas-phase nitro-PAH emissions for Vehicle #4

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	2.87± 1.40	1.34±N/A	6.55± 1.62	1.96± 1.23	2.26±N/A	6.22±N/A	3.06± 1.86
1-methyl-5-nitronaphthalene	0.18± 0.19	0.03± 0.02	0.23± 0.01	0.09± 0.07	0.03± 0.05	0.18± 0.22	0.12± 0.03
2-nitronaphthalene	1.40± 0.19	0.20± 0.02	0.66± 0.24	0.29± 0.11	0.22± 0.03	0.07±N/A	0.70± 0.19
2-nitrobiphenyl	0.13± 0.08	0.04± 0.00	0.05± 0.01	0.03± 0.00	0.03± 0.00	0.19± 0.24	0.08± 0.03
2-methyl-4-nitronaphthalene	0.34± 0.21	0.08± 0.00	0.22± 0.09	0.09± 0.05	0.08± 0.01	0.24± 0.30	0.13± 0.06
1-methyl-4-nitronaphthalene	0.27± 0.28	0.07± 0.02	0.14± 0.07	0.09± 0.05	0.07± 0.02	0.04±N/A	0.16± 0.07
1-methyl-6-nitronaphthalene	0.12± 0.12	0.04± 0.00	0.03± 0.00	0.03± 0.02	0.02± 0.01	0.01±N/A	0.09± 0.01
3-nitrobiphenyl	0.23± 0.20	0.09± 0.04	0.11± 0.04	0.08± 0.02	0.07± 0.00	0.20± 0.26	0.21± 0.13
4-nitrobiphenyl	0.14± 0.19	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.12± 0.17	0.00±N/A	0.14± 0.19
1,3-dinitronaphthalene	0.22± 0.12	0.12± 0.02	0.20± 0.01	0.17± 0.01	0.17± 0.01	0.06± 0.09	0.25± 0.06
1,5-dinitronaphthalene	0.00± 0.00	0.03± 0.02	0.02± 0.01	0.06± 0.06	0.00± 0.00	0.00±N/A	0.00±N/A

5-nitroacenaphthene	0.08± 0.11	0.04± 0.01	0.05± 0.02	0.04± 0.02	0.04± 0.02	0.09± 0.12	0.12± 0.12
2-nitrofluorene	0.01± 0.01	0.01± 0.02	0.01± 0.01	0.01± 0.01	0.00± 0.00	0.04± 0.06	0.12± 0.12
4-nitrophenanthrene	0.00±N/A	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9-nitroanthracene	0.25± 0.26	0.07± 0.04	0.12± 0.04	0.11± 0.07	0.10± 0.08	0.03±N/A	0.17± 0.11
9-nitrophenanthrene	0.01± 0.01	0.02± 0.03	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.29± 0.41	0.08± 0.12
1,8-dinitronaphthalene	0.02± 0.01	0.08± 0.10	0.04± 0.01	0.02± 0.00	0.02± 0.00	0.02± 0.02	0.46± 0.63
3-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrophenanthrene	0.00± 0.00	0.15± 0.21	0.44± 0.05	0.24± 0.33	0.00± 0.00	0.09±N/A	0.11± 0.15
2-nitroanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.32± 0.46	0.00± 0.00	0.00±N/A	0.04± 0.06
2-nitrofluoranthene	0.03± 0.05	0.13± 0.08	0.11± 0.01	0.08± 0.02	0.10± 0.03	0.00±N/A	0.17± 0.23
3-nitrofluoranthene	0.00± 0.00	0.03± 0.05	0.01± 0.02	0.01± 0.01	0.00± 0.00	0.40± 0.57	0.11± 0.15
4-nitropyrene	0.00± 0.00	0.03± 0.04	0.01± 0.01	0.01± 0.01	0.00± 0.00	0.34± 0.48	0.09± 0.13
1-nitropyrene	0.39± 0.46	0.15± 0.04	0.08± 0.03	0.05± 0.03	0.11± 0.06	0.42±N/A	0.23± 0.18
2-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00±N/A	0.00± 0.00	0.59± 0.34	0.26±N/A
2,7-dinitrofluoren-9-one	0.00± 0.00	0.00± 0.00	0.04± 0.06	0.11± 0.16	0.00± 0.00	0.22±N/A	0.00± 0.00
7-nitrobenz(a)anthracene	0.00± 0.00	0.06± 0.08	0.03± 0.04	0.00± 0.00	0.02± 0.03	0.00±N/A	0.22± 0.15
6-nitrochrysene	0.00± 0.00	0.03± 0.04	0.01± 0.01	0.00± 0.00	0.00± 0.00	0.11± 0.15	0.14± 0.20
3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.10± 0.14
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 1.23	N/A± 0.00
3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.87± 1.23	0.00± 0.00

Table D21: Gas-phase nitro-PAH emissions for Vehicle #5

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	5.09±N/A	0.84± 0.02	0.12± 0.17	0.93± 0.49	0.39± 0.20	0.60±N/A	0.18±N/A
1-methyl-5-nitronaphthalene	0.55± 0.12	0.12± 0.02	0.00± 0.00	0.14± 0.11	0.05± 0.01	0.29± 0.22	0.11± 0.10

2-nitronaphthalene	3.94±N/A	0.59± 0.04	0.09± 0.13	0.74± 0.44	0.28± 0.10	0.45±N/A	0.15±N/A
2-nitrobiphenyl	0.26± 0.19	0.14± 0.02	0.00± 0.00	0.09± 0.05	0.04± 0.01	0.14± 0.06	0.07± 0.10
2-methyl-4-nitronaphthalene	0.38± 0.24	0.16± 0.01	0.05± 0.07	0.13± 0.02	0.07± 0.02	0.16±N/A	0.27± 0.33
1-methyl-4-nitronaphthalene	0.42± 0.24	0.18± 0.03	0.05± 0.08	0.13± 0.03	0.06± 0.01	0.14± 0.05	0.17± 0.13
1-methyl-6-nitronaphthalene	0.17± 0.07	0.05± 0.02	0.02± 0.03	0.05± 0.02	0.04± 0.03	0.09±N/A	0.07± 0.07
3-nitrobiphenyl	0.49± 0.32	0.16± 0.02	0.06± 0.08	0.14± 0.02	0.07± 0.02	0.23± 0.10	0.18± 0.21
4-nitrobiphenyl	0.35±N/A	0.03± 0.04	0.03± 0.04	0.07± 0.03	0.03± 0.00	0.11±N/A	0.14± 0.20
1,3-dinitronaphthalene	0.25± 0.07	0.05± 0.07	0.06± 0.08	0.14± 0.02	0.13± 0.03	0.03± 0.04	0.13± 0.09
1,5-dinitronaphthalene	0.19± 0.03	0.08± 0.02	0.03± 0.04	0.05± 0.01	0.06± 0.01	0.08±N/A	0.05± 0.02
5-nitroacenaphthene	0.28± 0.11	0.12± 0.05	0.05± 0.07	0.09± 0.00	0.07± 0.02	0.07± 0.10	0.15± 0.22
2-nitrofluorene	0.12± 0.03	0.03± 0.00	0.02± 0.02	0.01± 0.00	0.02± 0.00	0.14± 0.12	0.11± 0.06
4-nitrophenanthrene	0.34± 0.45	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9-nitroanthracene	0.44±N/A	0.27± 0.03	0.03± 0.05	0.22± 0.09	0.11± 0.07	0.30± 0.08	0.29± 0.21
9-nitrophenanthrene	0.11± 0.03	0.03± 0.00	0.01± 0.02	0.01± 0.02	0.02± 0.00	0.24± 0.27	0.02± 0.03
1,8-dinitronaphthalene	0.27± 0.04	0.09± 0.03	0.03± 0.04	0.03± 0.01	0.04± 0.01	0.24± 0.11	0.04± 0.05
3-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrophenanthrene	0.11± 0.16	0.00± 0.00	0.01± 0.02	0.00± 0.00	0.00± 0.00	0.05± 0.07	0.06± 0.08
2-nitroanthracene	0.17± 0.14	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.32± 0.45	0.00± 0.00
2-nitrofluoranthene	0.17± 0.02	0.04± 0.01	0.01± 0.02	0.03± 0.01	0.06± 0.01	0.05± 0.07	0.06± 0.00
3-nitrofluoranthene	0.24± 0.20	0.02± 0.01	0.01± 0.01	0.01± 0.01	0.02± 0.03	0.03± 0.04	0.07± 0.05
4-nitropyrene	0.08± 0.01	0.03± 0.00	0.01± 0.01	0.00± 0.01	0.02± 0.02	0.05± 0.07	0.01± 0.02
1-nitropyrene	0.19± 0.03	0.12± 0.01	0.04± 0.06	0.04± 0.00	0.09± 0.01	0.38± 0.35	0.17±N/A
2-nitropyrene	0.12± 0.02	0.00± 0.00	0.00± 0.00	0.03± 0.04	0.09± 0.12	0.00± 0.00	0.00± 0.00
2,7-dinitrofluorene	0.12± 0.17	0.07± 0.05	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.16± 0.15	0.00± 0.00
2,7-dinitrofluoren-9-one	0.03± 0.04	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.23± 0.32	0.01± 0.01
7-nitrobenz(a)anthracene	0.09± 0.00	0.03± 0.01	0.00± 0.00	0.01± 0.01	0.02± 0.03	0.23± 0.17	0.00± 0.00
6-nitrochrysene	0.08± 0.03	0.03± 0.01	0.01± 0.01	0.00± 0.00	0.03± 0.04	0.13± 0.07	0.00± 0.00
3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.02± 0.03	0.00± 0.00
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00
3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D22: Gas-phase nitro-PAH emissions for Vehicle #6

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.91± 0.20	2.11± 1.02	0.40± 0.14	0.86± 0.07	0.73± 0.50	0.87±N/A	0.65±N/A
1-methyl-5-nitronaphthalene	0.18± 0.05	0.15±N/A	0.10± 0.05	0.38± 0.08	0.13± 0.03	0.55± 0.42	0.23± 0.13
2-nitronaphthalene	0.37± 0.03	0.40± 0.23	0.24± 0.09	0.24± 0.12	0.26±N/A	0.22±N/A	0.36± 0.15
2-nitrobiphenyl	0.11± 0.04	0.12± 0.11	0.03± 0.01	0.08± 0.08	0.16± 0.16	0.22± 0.22	0.06± 0.02
2-methyl-4-nitronaphthalene	0.08± 0.02	0.15± 0.21	0.08± 0.02	0.12± 0.03	0.23± 0.16	0.12±N/A	0.15± 0.09
1-methyl-4-nitronaphthalene	0.12± 0.04	0.20± 0.18	0.09± 0.03	0.13± 0.02	0.25± 0.10	0.07± 0.09	0.19± 0.07
1-methyl-6-nitronaphthalene	0.03± 0.02	0.01± 0.02	0.03± 0.03	0.00± 0.01	0.06± 0.02	0.03±N/A	0.02± 0.01
3-nitrobiphenyl	0.07± 0.01	0.08± 0.05	0.07± 0.03	0.06± 0.00	0.22± 0.21	0.48± 0.55	0.08± 0.01
4-nitrobiphenyl	0.00± 0.00	0.00± 0.00	0.03± 0.05	0.00± 0.00	0.04± 0.06	0.04±N/A	0.13± 0.18
1,3-dinitronaphthalene	0.10± 0.05	0.07± 0.01	0.10± 0.01	0.06± 0.03	0.16± 0.06	0.02± 0.03	0.16± 0.05
1,5-dinitronaphthalene	0.03± 0.04	0.01± 0.02	0.04± 0.01	0.02± 0.01	0.02± 0.02	0.03±N/A	0.02± 0.02
5-nitroacenaphthene	0.03± 0.04	0.00± 0.00	0.06± 0.00	0.02± 0.02	0.19± 0.07	0.03± 0.04	0.09± 0.06
2-nitrofluorene	0.14± 0.06	0.16± 0.03	0.02± 0.01	0.10± 0.12	0.18± 0.24	0.40± 0.53	0.01± 0.01
4-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.11± 0.15
9-nitroanthracene	0.12± 0.03	0.09± 0.01	0.10± 0.04	0.10± 0.06	0.44± 0.32	0.13± 0.03	0.28± 0.14
9-nitrophenanthrene	0.08± 0.04	0.18± 0.01	0.01± 0.01	0.03± 0.04	0.09± 0.13	0.00± 0.00	0.01± 0.01
1,8-dinitronaphthalene	0.04± 0.03	0.03± 0.01	0.04± 0.01	0.03± 0.01	0.04± 0.02	0.18± 0.23	0.02± 0.01
3-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrophenanthrene	0.16± 0.15	0.05± 0.07	0.00± 0.00	0.09± 0.13	0.00± 0.00	0.00± 0.00	0.11± 0.15
2-nitroanthracene	0.35± 0.49	0.84± 0.52	0.00± 0.00	0.06± 0.09	0.00±N/A	0.00± 0.00	0.07± 0.09
2-nitrofluoranthene	0.02± 0.02	0.02± 0.03	0.05± 0.02	0.05± 0.07	0.02± 0.02	0.39± 0.53	0.05± 0.01
3-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.01± 0.01	0.01± 0.02	0.00± 0.00	0.34± 0.48	0.00± 0.00
4-nitropyrene	0.00± 0.00	0.00± 0.00	0.06± 0.01	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

1-nitropyrene	0.28± 0.25	0.36± 0.10	0.13±N/A	0.06± 0.09	0.20± 0.21	0.30± 0.25	0.04± 0.06
2-nitropyrene	0.00± 0.00	0.00± 0.00	0.06± 0.08	0.00± 0.00	0.00± 0.00	0.00±N/A	0.00± 0.00
2,7-dinitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluoren-9-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00±N/A	0.08± 0.11
7-nitrobenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6-nitrochrysene	0.00± 0.00	0.00± 0.00	0.01± 0.01	0.00± 0.00	0.00± 0.00	0.09± 0.12	0.01± 0.01
3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00
3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D23: Gas-phase nitro-PAH emissions for Vehicle #7

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	3.35± 1.80	1.97± 0.55	18.83± 4.12	10.84± 2.27	10.17± 7.11	2.59± 2.14	1.51± 0.27
1-methyl-5-nitronaphthalene	5.39± 4.72	2.27± 1.33	9.73±N/A	7.68± 0.83	7.14± 3.78	3.39± 2.76	0.82± 0.59
2-nitronaphthalene	0.66± 0.39	0.58± 0.04	6.98± 6.44	0.61±N/A	0.46±N/A	0.21± 0.08	0.41± 0.09
2-nitrobiphenyl	0.06± 0.00	0.05± 0.01	0.23± 0.15	0.14± 0.12	0.07± 0.03	0.03± 0.02	0.04± 0.02
2-methyl-4-nitronaphthalene	0.77± 0.59	0.32± 0.12	6.79± 2.88	4.20± 4.19	1.16± 0.60	0.49± 0.38	0.18± 0.07
1-methyl-4-nitronaphthalene	0.46± 0.29	0.18± 0.06	0.54±N/A	0.00±N/A	0.54±N/A	0.44± 0.34	0.12± 0.04
1-methyl-6-nitronaphthalene	0.00± 0.01	0.00± 0.00	0.00±N/A	0.00±N/A	0.01± 0.01	0.01± 0.00	0.01± 0.00
3-nitrobiphenyl	0.06± 0.00	0.04± 0.02	0.10±N/A	0.07±N/A	0.08± 0.01	0.04± 0.00	0.06± 0.01
4-nitrobiphenyl	0.01± 0.01	0.00± 0.00	0.00±N/A	0.00± 0.00	0.00± 0.00	0.02± 0.01	0.04± 0.00
1,3-dinitronaphthalene	0.03± 0.03	0.09± 0.06	0.03± 0.04	0.01± 0.01	0.04± 0.01	0.03± 0.00	0.03± 0.00
1,5-dinitronaphthalene	0.01± 0.01	0.02± 0.02	0.00±N/A	0.01±N/A	0.02± 0.02	0.02± 0.00	0.01± 0.00
5-nitroacenaphthene	0.01± 0.02	0.02± 0.03	0.00± 0.00	0.01± 0.02	0.04± 0.05	0.04± 0.01	0.05± 0.01
2-nitrofluorene	0.04± 0.05	0.16± 0.10	0.27± 0.16	0.18± 0.23	0.04± 0.02	0.01± 0.00	0.01± 0.00
4-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

9-nitroanthracene	0.10± 0.00	0.10± 0.05	0.04± 0.06	0.03± 0.04	0.13± 0.06	0.07± 0.01	0.10± 0.01
9-nitrophenanthrene	0.04± 0.04	0.06± 0.09	0.22± 0.16	0.00± 0.01	0.03± 0.00	0.02± 0.01	0.00± 0.00
1,8-dinitronaphthalene	0.01± 0.00	0.04± 0.02	0.14± 0.17	0.12± 0.16	0.04± 0.06	0.02± 0.01	0.01± 0.00
3-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrophenanthrene	0.05± 0.07	0.28± 0.05	0.05± 0.07	0.00± 0.00	0.03± 0.04	0.00± 0.00	0.00± 0.00
2-nitroanthracene	0.20± 0.28	0.36± 0.51	0.17± 0.23	0.00± 0.00	0.03± 0.04	0.00± 0.00	0.00± 0.00
2-nitrofluoranthene	0.01± 0.01	0.04± 0.05	0.00± 0.00	0.01± 0.01	0.03± 0.04	0.01± 0.01	0.00± 0.01
3-nitrofluoranthene	0.00± 0.00	0.20± 0.22	0.37± 0.52	0.00± 0.00	0.02± 0.03	0.00± 0.00	0.00± 0.00
4-nitropyrene	0.00± 0.00	0.05± 0.05	0.20± 0.28	0.00± 0.00	0.03± 0.04	0.01± 0.01	0.00± 0.00
1-nitropyrene	0.07± 0.02	0.28± 0.30	0.22± 0.13	0.02± 0.03	0.09± 0.01	0.03± 0.01	0.15± 0.14
2-nitropyrene	0.00± 0.00	0.10± 0.15	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2,7-dinitrofluorene	0.00± 0.00	0.02± 0.02	0.00± 0.00	0.00± 0.00	0.02± 0.03	0.01± 0.01	0.00± 0.00
2,7-dinitrofluoren-9-one	0.00± 0.00	0.00± 0.00	0.00±N/A	0.00±N/A	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-nitrobenz(a)anthracene	0.00± 0.00	0.04± 0.06	0.00± 0.00	0.00± 0.00	0.03± 0.04	0.01± 0.01	0.00± 0.00
6-nitrochrysene	0.00± 0.00	0.02± 0.03	0.15± 0.22	0.00± 0.00	0.03± 0.04	0.00± 0.00	0.00± 0.00
3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00	N/A± 0.00
3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D24: Gas-phase nitro-PAH emissions for Vehicle #8

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	5.92± 3.46	5.00± 1.28	6.85± 3.39	13.76± 5.72	7.92± 8.19	5.13± 1.18	5.38± 0.52
1-methyl-5-nitronaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.65± 0.78	0.00± 0.00	0.24± 0.00
2-nitronaphthalene	4.01± 0.80	3.13± 0.33	5.13± 0.83	5.11± 1.13	2.31± 2.63	4.08± 0.44	0.69± 0.04
2-nitrobiphenyl	0.54± 0.15	0.89± 0.26	0.86± 0.70	0.86± 0.19	0.12± 0.12	1.34± 0.30	0.11± 0.04
2-methyl-4-nitronaphthalene	0.79± 0.42	0.75± 0.65	1.38± 0.83	1.11± 0.05	0.37± 0.44	0.82± 0.41	0.09± 0.00

1-methyl-4-nitronaphthalene	0.54± 0.43	1.04± 0.13	1.10± 0.76	1.07± 0.05	0.37± 0.43	0.73± 0.21	0.21± 0.05
1-methyl-6-nitronaphthalene	0.31± 0.38	0.93± 0.28	1.05± 0.90	0.72± 0.05	0.61± 0.87	0.77± 0.37	1.08± 0.22
3-nitrobiphenyl	0.37± 0.12	0.29± 0.06	0.26± 0.03	0.21± 0.08	0.07± 0.07	0.28± 0.05	0.08± 0.03
4-nitrobiphenyl	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.29± 0.41	0.00± 0.00	0.39± 0.02
1,3-dinitronaphthalene	1.33± 0.25	1.45± 0.08	1.93± 0.11	0.92± 0.25	0.08± 0.04	1.75± 0.23	0.22± 0.17
1,5-dinitronaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.06± 0.08	0.00± 0.00	0.09± 0.02
5-nitroacenaphthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.07± 0.09	0.06± 0.11	0.16± 0.02
4-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
9-nitroanthracene	0.35± 0.20	0.17± 0.09	0.23± 0.11	0.11± 0.16	0.12± 0.07	0.12± 0.10	0.15± 0.02
9-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.04± 0.06	0.00± 0.00	0.08± 0.00
1,8-dinitronaphthalene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.03± 0.00	0.00± 0.00	0.03± 0.00
3-nitrophenanthrene	0.87± 1.51	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitrophenanthrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
2-nitroanthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.30± 0.43	0.00± 0.00	0.18± 0.25
2-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrofluoranthene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
4-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.18± 0.12	0.00± 0.00	0.26± 0.14
2-nitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.97± 1.36
2,7-dinitrofluorene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.01± 0.01	0.00± 0.00	0.01± 0.01
2,7-dinitrofluoren-9-one	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
7-nitrobenz(a)anthracene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6-nitrochrysene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
3-nitrobenzanthrone	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,3-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,6-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1,8-dinitropyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
6a+1e-nitrobenzpyrene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00
1-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	N/A±N/A	0.00± 0.00	N/A±N/A

3-nitrobenzo[e]pryene	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00

Table D25: Particle-phase nitro-PAH emissions for Vehicle #1

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.00±0.00	0.03±0.02	0.08±0.05	0.01±0.01	0.00±0.00	0.12±0.07	0.01±0.02
1-methyl-5-nitronaphthalene	0.01±0.02	0.07±0.08	0.00±0.00	0.00±0.00	0.02±0.03	0.07±0.07	0.00±0.00
2-nitronaphthalene	0.01±0.01	0.05±0.01	0.04±0.02	0.02±0.01	0.00±0.00	0.02±0.00	0.02±0.00
2-nitrobiphenyl	0.03±0.00	0.03±0.04	0.03±0.03	0.02±0.01	0.00±0.00	0.02±0.02	0.03±0.00
2-methyl-4-nitronaphthalene	0.01±0.02	0.04±0.02	0.01±0.01	0.01±0.01	0.00±0.00	0.04±0.02	0.02±0.02
1-methyl-4-nitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-methyl-6-nitronaphthalene	0.00±0.00	0.03±0.05	0.10±0.15	0.00±0.00	0.00±0.00	0.05±0.08	0.07±0.09
3-nitrobiphenyl	0.00±0.00	0.00±0.01	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.01	0.00±0.00
4-nitrobiphenyl	0.21±0.13	0.38±0.45	0.81±0.08	0.24±0.20	0.52±0.73	0.10±0.14	0.27±0.15
1,3-dinitronaphthalene	0.00±0.00	0.15±0.21	0.47±0.32	0.10±0.14	0.06±0.09	0.13±0.18	0.00±0.00
1,5-dinitronaphthalene	0.03±0.04	0.04±0.06	0.10±0.15	0.00±0.00	0.12±0.17	0.03±0.04	0.00±0.00
5-nitroacenaphthene	0.00±0.00	0.07±0.10	0.09±0.13	0.04±0.06	0.00±0.00	0.00±0.00	0.00±0.01
2-nitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
4-nitrophenanthrene	0.21±0.02	0.07±0.00	0.12±0.06	0.14±0.07	0.16±0.06	0.09±0.01	0.06±0.07
9-nitroanthracene	0.00±0.00	0.00±0.00	0.06±0.03	0.00±0.00	0.03±0.04	0.00±0.00	0.00±0.00
9-nitrophenanthrene	0.00±0.00	0.30±0.42	4.16±5.88	1.15±1.62	0.23±0.33	0.00±0.00	0.01±0.02
1,8-dinitronaphthalene	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.06±0.02	0.02±0.03	0.00±0.00
3-nitrophenanthrene	0.53±0.04	0.38±0.08	0.60±0.21	0.58±0.09	0.29±0.41	0.46±0.08	0.13±0.09
2-nitrophenanthrene	0.05±0.07	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitroanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrofluoranthene	0.04±0.00	0.00±0.00	0.07±0.05	0.01±0.01	0.05±0.02	0.03±0.05	0.00±0.00
3-nitrofluoranthene	0.00±0.00	0.00±0.00	0.07±0.10	0.00±0.00	0.00±0.00	0.04±0.06	0.00±0.00
4-nitropyrene	0.00±0.00	0.06±0.00	0.12±0.03	0.00±0.00	0.03±0.05	0.00±0.00	0.00±0.00
1-nitropyrene	0.10±0.04	0.13±0.00	0.41±0.13	0.10±0.04	0.15±0.07	0.13±0.09	0.07±0.02
2-nitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-nitrobenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6-nitrochrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D26: Particle-phase nitro-PAH emissions for Vehicle #2

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.04±0.06	0.03±0.00	0.03±0.05	0.00±0.00	0.04±0.00	0.04±0.01	0.11±0.00
1-methyl-5-nitronaphthalene	0.01±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.01	0.07±0.01
2-nitronaphthalene	0.02±0.03	0.02±0.03	0.10±0.01	0.03±0.01	0.03±0.01	0.03±0.02	0.02±0.01
2-nitrobiphenyl	0.00±0.00	0.05±0.02	0.09±0.02	0.02±0.03	0.04±0.01	0.02±0.02	0.02±0.02
2-methyl-4-nitronaphthalene	0.03±0.05	0.03±0.04	0.07±0.01	0.02±0.00	0.06±0.03	0.03±0.01	0.10±0.00
1-methyl-4-nitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-methyl-6-nitronaphthalene	0.00±0.00	0.11±0.16	0.15±0.21	0.00±0.00	0.05±0.06	0.09±0.13	0.07±0.11
3-nitrobiphenyl	0.02±0.02	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.01	0.00±0.00	0.00±0.00
4-nitrobiphenyl	0.85±0.28	0.28±0.40	2.33±0.04	0.09±0.12	0.12±0.17	0.22±0.31	0.35±0.22
1,3-dinitronaphthalene	0.23±0.33	0.62±0.03	0.24±0.35	0.53±0.46	0.24±0.04	0.18±0.25	0.01±0.01
1,5-dinitronaphthalene	0.00±0.00	0.00±0.00	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
5-nitroacenaphthene	0.11±0.05	0.04±0.00	0.34±0.48	0.00±0.00	0.02±0.03	0.10±0.02	0.00±0.01
2-nitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.02±0.03	0.00±0.00
4-nitrophenanthrene	0.30±0.22	0.10±0.06	0.18±0.07	0.11±0.04	0.11±0.03	0.07±0.02	0.12±0.03
9-nitroanthracene	0.10±0.05	0.00±0.00	0.03±0.05	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
9-nitrophenanthrene	1.51±0.13	1.60±0.16	1.90±2.69	0.12±0.17	1.15±1.63	1.45±0.04	1.33±1.28
1,8-dinitronaphthalene	0.14±0.02	0.07±0.10	0.07±0.03	0.01±0.02	0.03±0.05	0.02±0.03	0.02±0.03

3-nitrophenanthrene	1.38±0.64	0.78±0.19	0.88±0.10	0.69±0.05	0.52±0.11	0.96±0.35	1.35±0.82
2-nitrophenanthrene	0.00±0.00	0.06±0.08	0.04±0.06	0.00±0.00	0.06±0.09	0.03±0.04	0.04±0.06
2-nitroanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrofluoranthene	0.16±0.16	0.00±0.00	0.07±0.05	0.02±0.03	0.00±0.00	0.14±0.04	0.15±0.11
3-nitrofluoranthene	0.03±0.04	0.00±0.00	0.02±0.03	0.00±0.00	0.00±0.00	0.08±0.09	0.00±0.00
4-nitropyrene	0.16±0.04	0.04±0.06	0.09±0.02	0.05±0.08	0.03±0.04	0.03±0.05	0.00±0.00
1-nitropyrene	1.04±0.95	0.29±0.01	0.65±0.25	0.45±0.12	0.19±0.14	0.36±0.12	0.37±0.05
2-nitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-nitrobenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6-nitrochrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D27: Particle-phase nitro-PAH emissions for Vehicle #3

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.01±0.02	0.01±0.00	0.01±0.00	0.12±0.05	0.03±0.01	0.01±0.01	0.03±0.01
1-methyl-5-nitronaphthalene	0.01±0.01	0.00±0.00	0.00±0.00	0.03±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitronaphthalene	0.03±0.03	0.01±0.01	0.02±0.00	0.11±0.02	0.03±0.01	0.03±0.00	0.04±0.01
2-nitrobiphenyl	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-methyl-4-nitronaphthalene	0.02±0.03	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.01	0.01±0.01	0.00±0.00
1-methyl-4-nitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.08±0.12	0.05±0.08	0.00±0.00
1-methyl-6-nitronaphthalene	0.01±0.02	0.00±0.00	0.02±0.03	0.14±0.20	0.02±0.03	0.00±0.00	0.06±0.04
3-nitrobiphenyl	0.00±0.01	0.00±0.00	0.00±0.00	0.01±0.01	0.01±0.00	0.00±0.00	0.00±0.00

4-nitrobiphenyl	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.01	0.18±0.25	0.00±0.00	0.00±0.00
1,3-dinitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.05±0.07	0.00±0.00	0.00±0.00
1,5-dinitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.05±0.07	0.00±0.00	0.00±0.00
5-nitroacenaphthene	0.00±0.01	0.03±0.02	0.00±0.00	0.02±0.03	0.01±0.02	0.00±0.00	0.00±0.00
2-nitrofluorene	0.00±0.00	0.00±0.00	0.00±0.01	0.08±0.11	0.00±0.00	0.00±0.00	0.00±0.00
4-nitrophenanthrene	0.03±0.00	0.01±0.01	0.02±0.00	0.14±0.06	0.04±0.02	0.05±0.01	0.04±0.04
9-nitroanthracene	0.03±0.01	0.00±0.00	0.02±0.03	0.10±0.00	0.02±0.02	0.00±0.01	0.05±0.05
9-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,8-dinitronaphthalene	0.02±0.01	0.05±0.02	0.02±0.00	0.02±0.01	0.01±0.01	0.01±0.01	0.01±0.01
3-nitrophenanthrene	0.10±0.03	0.15±0.01	0.65±0.60	0.54±0.57	0.20±0.07	0.23±0.07	0.97±1.10
2-nitrophenanthrene	0.02±0.03	0.03±0.01	0.07±0.02	0.00±0.00	0.08±0.04	0.01±0.01	0.03±0.04
2-nitroanthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrofluoranthene	0.00±0.00	0.05±0.04	0.00±0.00	0.00±0.00	0.01±0.02	0.00±0.00	0.03±0.04
3-nitrofluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
4-nitropyrene	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.01	0.02±0.02	0.02±0.02
1-nitropyrene	0.04±0.01	0.06±0.04	0.05±0.01	0.06±0.01	0.16±0.10	0.10±0.00	0.09±0.02
2-nitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.04
2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-nitrobenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6-nitrochrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D28: Particle-phase nitro-PAH emissions for Vehicle #4

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.06±0.04	0.09±0.00	0.28±0.13	0.33±0.36	0.31±0.21	0.09±N/A	0.11±0.09
1-methyl-5-nitronaphthalene	0.02±0.01	0.01±0.00	0.02±0.02	0.07±0.06	0.00±N/A	0.08±0.11	0.01±0.02
2-nitronaphthalene	0.06±0.04	0.07±0.02	0.08±0.09	0.29±0.29	0.21±0.06	0.28±0.33	0.08±0.04
2-nitrobiphenyl	0.02±0.01	0.02±0.00	0.02±0.01	0.09±0.12	0.05±0.07	0.14±0.20	0.06±0.06
2-methyl-4-nitronaphthalene	0.03±0.01	0.02±0.01	0.02±0.03	0.10±0.10	0.06±0.02	0.09±0.12	0.02±0.01
1-methyl-4-nitronaphthalene	0.03±0.01	0.03±0.00	0.04±0.02	0.12±0.13	0.44±0.54	0.20±0.19	0.07±0.05
1-methyl-6-nitronaphthalene	0.01±0.00	0.01±0.00	0.01±0.00	0.06±0.07	0.19±0.27	0.27±0.38	0.02±0.03
3-nitrobiphenyl	0.06±0.01	0.04±0.01	0.05±0.02	0.20±0.21	0.17±0.16	0.13±0.12	0.06±0.01
4-nitrobiphenyl	0.00±0.00	0.00±0.00	0.00±0.00	0.05±0.07	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitronaphthalene	0.13±0.05	0.20±0.02	0.16±0.01	0.33±0.27	0.20±N/A	0.33±N/A	0.22±0.10
1,5-dinitronaphthalene	0.03±0.00	0.02±0.00	0.03±0.01	0.33±0.44	0.20±0.28	0.24±0.32	0.10±0.12
5-nitroacenaphthene	0.05±0.01	0.03±0.00	0.05±0.03	0.14±0.13	0.13±0.12	0.06±0.03	0.05±0.01
2-nitrofluorene	0.07±0.00	0.03±0.00	0.02±0.02	0.36±0.51	0.16±0.22	0.17±0.25	0.25±0.34
4-nitrophenanthrene	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
9-nitroanthracene	0.09±0.08	0.09±0.05	0.11±0.03	0.39±0.47	0.23±0.31	0.28±0.34	0.16±0.19
9-nitrophenanthrene	0.10±0.05	0.02±0.03	0.11±0.07	0.00±0.00	0.06±0.09	0.00±0.00	0.00±0.00
1,8-dinitronaphthalene	0.09±0.00	0.06±0.01	0.04±0.00	0.04±N/A	0.43±0.61	0.33±0.42	0.21±0.23
3-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrophenanthrene	0.06±0.08	0.03±0.04	0.03±0.05	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitroanthracene	0.00±0.00	0.00±0.00	0.12±0.16	0.00±0.00	0.11±0.16	0.00±0.00	0.16±0.22
2-nitrofluoranthene	0.07±0.01	0.05±0.07	0.05±0.01	0.00±0.00	0.23±0.33	0.22±0.31	0.15±0.13
3-nitrofluoranthene	0.08±0.00	0.02±0.03	0.07±0.06	0.00±0.00	0.15±0.21	0.23±0.32	0.13±0.19
4-nitropyrene	0.04±0.01	0.01±0.01	0.05±0.05	0.00±0.00	0.16±0.22	0.11±0.16	0.08±0.08
1-nitropyrene	0.26±0.14	0.16±0.16	0.13±N/A	0.28±N/A	0.09±N/A	0.11±N/A	0.29±0.05
2-nitropyrene	0.00±0.00	0.00±N/A	0.00±0.00	0.00±N/A	0.00±N/A	0.00±N/A	0.00±0.00
2,7-dinitrofluorene	0.07±0.00	0.00±0.00	0.00±0.00	0.00±N/A	0.00±N/A	0.00±N/A	0.00±N/A
2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-nitrobenz(a)anthracene	0.09±0.00	0.05±0.02	0.00±0.00	0.06±N/A	0.25±0.36	0.15±0.22	0.22±0.07
6-nitrochrysene	0.04±0.00	0.03±0.00	0.00±0.00	0.00±N/A	0.12±0.17	0.07±0.10	0.06±0.08

3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±N/A	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.33±0.03	0.11±0.16	0.22±0.30	0.12±0.17	0.86±0.13	0.00±0.00	0.00±0.00
1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.33±0.47	0.08±0.11	0.00±0.00	0.00±0.00
1-nitrobenzo[e]pryene	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D29: Particle-phase nitro-PAH emissions for Vehicle #5

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.06±0.04	0.14±0.07	0.22±0.10	0.23±0.00	0.31±0.33	0.13±0.03	0.11±0.09
1-methyl-5-nitronaphthalene	0.01±0.00	0.01±0.01	0.01±0.02	0.03±0.02	0.00±0.00	0.08±0.01	0.02±0.00
2-nitronaphthalene	0.05±0.02	0.12±0.08	0.16±0.02	0.17±0.03	0.34±0.37	0.13±0.02	0.11±0.10
2-nitrobiphenyl	0.02±0.01	0.02±0.01	0.05±0.02	0.06±0.05	0.03±0.04	0.02±0.03	0.03±0.01
2-methyl-4-nitronaphthalene	0.02±0.02	0.04±0.03	0.08±0.01	0.03±0.04	0.05±0.07	0.00±0.00	0.04±0.03
1-methyl-4-nitronaphthalene	0.03±0.01	0.05±0.02	0.12±0.02	0.09±0.04	0.08±0.05	0.11±0.04	0.04±0.02
1-methyl-6-nitronaphthalene	0.00±0.00	0.00±0.00	0.03±0.03	0.01±0.01	0.01±0.01	0.03±0.05	0.01±0.00
3-nitrobiphenyl	0.03±0.01	0.04±0.03	0.11±0.01	0.07±0.01	0.09±0.09	0.09±0.03	0.06±0.03
4-nitrobiphenyl	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitronaphthalene	0.17±0.01	0.18±0.00	0.51±0.26	0.35±0.23	0.46±0.32	0.68±0.04	0.32±0.02
1,5-dinitronaphthalene	0.02±0.01	0.01±0.00	0.11±0.16	0.08±0.11	0.00±0.00	0.00±0.00	0.02±0.01
5-nitroacenaphthene	0.01±0.01	0.02±0.01	0.07±0.04	0.01±0.02	0.03±0.04	0.05±0.03	0.03±0.00
2-nitrofluorene	0.01±0.01	0.00±0.00	0.15±0.21	0.09±0.12	0.00±0.00	0.09±0.13	0.02±0.02
4-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.06	0.00±0.00	0.00±0.00	0.00±0.00
9-nitroanthracene	0.05±0.03	0.07±0.02	0.30±0.14	0.08±0.01	0.10±0.04	0.29±0.19	0.09±0.03
9-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.02
1,8-dinitronaphthalene	0.02±0.00	0.02±0.01	0.20±0.22	0.07±0.07	0.00±0.00	0.11±0.16	0.06±0.04
3-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.06
2-nitroanthracene	0.00±0.00	0.00±0.00	0.00±N/A	0.00±0.00	0.00±0.00	0.00±0.00	0.13±0.19

2-nitrofluoranthene	0.02±0.03	0.03±0.05	0.00±N/A	0.18±0.04	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrofluoranthene	0.00±0.00	0.00±0.00	0.09±0.13	0.00±0.00	0.00±0.00	0.08±0.12	0.06±0.09
4-nitropyrene	0.00±0.00	0.00±0.00	0.07±0.10	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.06
1-nitropyrene	0.08±0.12	0.09±0.04	0.41±N/A	0.17±0.11	0.74±0.89	0.61±0.04	0.21±0.04
2-nitropyrene	0.00±0.00	0.00±0.00	0.00±N/A	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluorene	0.00±0.00	0.00±0.00	0.00±N/A	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.02
2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.03±0.04	0.00±0.00	0.00±0.00	0.02±0.03	0.00±0.00
7-nitrobenz(a)anthracene	0.02±0.02	0.02±0.02	0.10±0.14	0.03±0.05	0.04±0.05	0.12±0.16	0.03±0.05
6-nitrochrysene	0.01±0.01	0.00±0.00	0.05±0.07	0.00±0.00	0.00±0.00	0.02±0.03	0.01±0.02
3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.12±0.17	0.42±0.13	0.00±0.00	0.49±0.02	0.00±0.00	0.00±0.00	0.36±0.09
1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-nitrobenzo[e]pryene	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.78±1.10	0.13±0.19	0.00±0.00

Table D30: Particle-phase nitro-PAH emissions for Vehicle #6

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.07±0.00	0.07±0.01	0.02±0.03	0.15±0.01	0.10±0.10	0.18±0.11	0.22±0.23
1-methyl-5-nitronaphthalene	0.01±0.02	0.01±0.02	0.01±0.01	0.02±0.00	0.02±0.01	0.01±0.01	0.03±0.01
2-nitronaphthalene	0.07±0.04	0.06±0.05	0.02±0.02	0.09±0.02	0.08±0.08	0.18±0.09	0.13±0.12
2-nitrobiphenyl	0.01±0.01	0.01±0.01	0.01±0.01	0.11±0.02	0.05±0.07	0.05±0.07	0.04±0.01
2-methyl-4-nitronaphthalene	0.02±0.03	0.02±0.02	0.00±0.00	0.05±0.00	0.02±0.03	0.04±0.06	0.04±0.06
1-methyl-4-nitronaphthalene	0.05±0.01	0.04±0.01	0.00±0.00	0.09±0.02	0.05±0.07	0.06±0.03	0.08±0.02
1-methyl-6-nitronaphthalene	0.00±0.00	0.01±0.00	0.00±0.00	0.01±0.01	0.01±0.01	0.02±0.01	0.04±0.01
3-nitrobiphenyl	0.04±0.03	0.05±0.01	0.01±0.01	0.06±0.03	0.04±0.05	0.10±0.03	0.10±0.02
4-nitrobiphenyl	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.12±0.01
1,3-dinitronaphthalene	0.32±0.10	0.25±0.04	0.21±0.01	0.31±0.01	0.33±0.16	0.30±0.03	0.22±0.11
1,5-dinitronaphthalene	0.04±0.04	0.00±0.01	0.00±0.00	0.07±0.01	0.05±0.07	0.00±0.00	0.13±0.04

5-nitroacenaphthene	0.01±0.02	0.02±0.02	0.00±0.00	0.02±0.01	0.02±0.02	0.04±0.02	0.17±0.06
2-nitrofluorene	0.05±0.07	0.00±0.00	0.00±0.00	0.11±0.02	0.08±0.11	0.00±0.00	0.29±0.09
4-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.08±0.11	0.00±0.00
9-nitroanthracene	0.10±0.03	0.12±0.03	0.00±0.00	0.23±0.05	0.19±0.24	0.27±0.15	0.24±0.00
9-nitrophenanthrene	0.17±0.20	0.03±0.00	0.00±0.00	0.01±0.02	0.00±0.00	0.02±0.03	0.21±0.12
1,8-dinitronaphthalene	0.06±0.05	0.02±0.00	0.00±0.00	0.09±0.02	0.04±0.05	0.01±0.01	0.40±0.13
3-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.28±0.07
2-nitroanthracene	0.00±0.00	0.00±0.00	0.00±N/A	0.00±0.00	0.17±0.24	0.23±0.33	0.12±0.17
2-nitrofluoranthene	0.11±0.10	0.03±0.00	0.00±0.00	0.07±0.05	0.05±0.07	0.00±0.00	0.39±0.05
3-nitrofluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.02±0.03	0.00±0.00	0.00±0.00	0.61±0.04
4-nitropyrene	0.01±0.01	0.00±0.00	0.00±0.00	0.00±0.01	0.00±0.00	0.00±0.00	0.39±0.09
1-nitropyrene	0.22±0.06	0.11±0.02	0.08±0.02	0.28±0.01	0.42±0.50	0.42±0.12	0.71±0.14
2-nitropyrene	0.00±0.00	0.10±0.14	0.00±0.00	0.07±0.10	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.36±0.01
2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.04
7-nitrobenz(a)anthracene	0.00±0.00	0.03±0.05	0.00±0.00	0.00±0.00	0.02±0.02	0.00±0.00	0.65±0.29
6-nitrochrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.28±0.12
3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.27±0.38	0.13±0.19	0.00±0.00	0.14±0.19	0.28±0.08	0.20±0.29	0.00±0.00
1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.10±0.14
1-nitrobenzo[e]pryene	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D31: Particle-phase nitro-PAH emissions for Vehicle #7

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.06±0.00	0.05±0.02	0.06±0.02	0.13±0.04	0.16±N/A	0.05±0.06	0.06±0.04
1-methyl-5-nitronaphthalene	0.02±0.01	0.01±0.00	0.03±0.01	0.05±0.04	0.06±0.04	0.01±0.01	0.01±0.00

2-nitronaphthalene	0.05±0.01	0.04±0.02	0.04±0.00	0.08±0.04	0.10±N/A	0.04±0.06	0.06±0.05
2-nitrobiphenyl	0.02±0.00	0.02±0.01	0.03±0.02	0.04±0.04	0.04±N/A	0.01±0.01	0.02±0.01
2-methyl-4-nitronaphthalene	0.02±0.00	0.01±0.01	0.03±0.01	0.05±0.02	0.08±N/A	0.01±0.02	0.02±0.02
1-methyl-4-nitronaphthalene	0.02±0.00	0.02±0.01	0.03±0.00	0.05±0.02	0.07±N/A	0.02±0.02	0.03±0.02
1-methyl-6-nitronaphthalene	0.01±0.00	0.00±0.00	0.01±0.00	0.01±0.01	0.05±0.07	0.00±0.00	0.01±0.00
3-nitrobiphenyl	0.03±0.01	0.02±0.01	0.02±0.00	0.03±0.01	0.05±N/A	0.01±0.01	0.04±0.03
4-nitrobiphenyl	0.02±0.03	0.00±0.00	0.00±0.00	0.02±0.02	0.00±0.00	0.00±0.00	0.10±0.14
1,3-dinitronaphthalene	0.07±0.00	0.11±0.04	0.19±0.09	0.10±0.03	0.13±0.02	0.14±0.07	0.08±0.03
1,5-dinitronaphthalene	0.01±0.00	0.00±0.00	0.02±0.02	0.01±0.02	0.02±0.00	0.01±0.00	0.02±0.01
5-nitroacenaphthene	0.02±0.01	0.01±0.01	0.02±0.03	0.03±0.03	0.02±N/A	0.00±0.01	0.02±0.00
2-nitrofluorene	0.00±0.00	0.00±0.00	0.06±0.09	0.05±0.08	0.00±0.00	0.00±0.00	0.01±0.01
4-nitrophenanthrene	0.00±0.00	0.00±0.00	0.03±0.04	0.00±0.00	0.00±0.00	0.00±0.00	0.07±0.03
9-nitroanthracene	0.05±0.02	0.03±0.05	0.09±0.06	0.09±0.05	1.04±N/A	0.12±0.01	0.07±0.04
9-nitrophenanthrene	0.03±0.05	0.00±0.00	0.08±0.02	0.08±0.02	0.09±0.07	0.05±0.04	0.04±0.01
1,8-dinitronaphthalene	0.03±0.04	0.01±0.00	0.05±0.07	0.02±0.03	0.02±0.01	0.00±0.00	0.05±0.03
3-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrophenanthrene	0.00±0.00	0.00±0.00	0.02±0.03	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.05
2-nitroanthracene	0.07±0.10	0.00±0.00	0.00±0.00	0.04±0.06	0.10±0.14	0.00±0.00	0.00±0.00
2-nitrofluoranthene	0.00±0.00	0.02±0.00	0.04±0.06	0.00±0.00	0.09±0.09	0.00±0.00	0.06±0.02
3-nitrofluoranthene	0.04±0.06	0.00±0.00	0.06±0.09	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.02
4-nitropyrene	0.01±0.02	0.00±0.00	0.05±0.07	0.00±0.00	0.00±0.00	0.00±0.00	0.02±0.01
1-nitropyrene	0.11±0.01	0.07±0.02	0.15±0.15	0.13±0.11	0.04±0.01	0.02±0.00	0.08±0.01
2-nitropyrene	1.05±1.49	0.00±0.00	0.26±0.37	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluorene	0.00±N/A	0.00±0.00	0.02±0.04	0.01±0.02	0.00±0.00	0.00±0.00	0.06±0.08
2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.02±0.03	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
7-nitrobenz(a)anthracene	0.09±0.12	0.00±0.00	0.08±0.11	0.03±0.04	0.04±0.06	0.00±0.00	0.03±0.02
6-nitrochrysene	0.00±0.00	0.00±0.00	0.03±0.05	0.01±0.02	0.00±0.00	0.00±0.00	0.02±0.01
3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.04	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.16±0.03	0.21±0.05	0.12±0.17	0.11±0.15	0.39±0.04	0.33±0.08	0.35±0.01

1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-nitrobenzo[e]pryene	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A	N/A±N/A
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D32: Particle-phase nitro-PAH emissions for Vehicle #8

Component (ng/mile)	A	B	C	D	E	F	G
1-nitronaphthalene	0.26±0.34	0.00±0.00	0.00±0.00	0.29±0.41	0.10±0.03	0.00±0.00	0.10±0.01
1-methyl-5-nitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.00	0.00±0.00	0.01±0.01
2-nitronaphthalene	0.05±0.10	0.00±0.00	0.00±0.00	0.13±0.18	0.07±0.05	0.00±0.00	0.09±0.00
2-nitrobiphenyl	0.23±0.40	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.00	0.00±0.00	0.05±0.01
2-methyl-4-nitronaphthalene	0.05±0.09	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.01	0.00±0.00	0.03±0.00
1-methyl-4-nitronaphthalene	0.00±0.00	0.00±0.00	0.05±0.09	0.00±0.00	0.05±0.01	0.00±0.00	0.04±0.01
1-methyl-6-nitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.01	0.00±0.00	0.01±0.00
3-nitrobiphenyl	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.00	0.00±0.00	0.04±0.01
4-nitrobiphenyl	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.13±0.18
1,3-dinitronaphthalene	0.24±0.42	0.14±0.11	0.00±0.00	0.52±0.43	0.30±0.07	0.00±0.00	0.22±0.06
1,5-dinitronaphthalene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.03±0.00	0.00±0.00	0.01±0.01
5-nitroacenaphthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.01	0.00±0.00	0.04±0.03
2-nitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.12±0.02	0.00±0.00	0.04±0.06
4-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.06±0.08
9-nitroanthracene	0.09±0.16	0.15±0.14	0.00±0.00	0.00±0.00	0.10±0.01	0.11±0.18	0.13±0.02
9-nitrophenanthrene	0.04±0.06	0.04±0.08	0.00±0.00	0.00±0.00	0.04±0.01	0.00±0.00	0.02±0.03
1,8-dinitronaphthalene	0.30±0.22	0.22±0.31	0.08±0.13	0.61±0.86	0.08±0.02	0.13±0.22	0.03±0.01
3-nitrophenanthrene	0.00±0.00	0.17±0.05	0.06±0.11	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrophenanthrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.05±0.07
2-nitroanthracene	0.19±0.32	0.00±0.00	0.00±0.00	0.26±0.37	0.00±0.00	0.00±0.00	0.00±0.00
2-nitrofluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.07±0.02	0.00±0.00	0.08±0.00
3-nitrofluoranthene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.06	0.00±0.00	0.03±0.03
4-nitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.01	0.00±0.00	0.00±0.01

1-nitropyrene	0.24±0.03	0.27±0.09	0.00±0.00	0.12±0.17	0.22±0.05	0.00±0.00	0.17±0.04
2-nitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluorene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
2,7-dinitrofluoren-9-one	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.01
7-nitrobenz(a)anthracene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.06	0.00±0.00	0.02±0.01
6-nitrochrysene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
3-nitrobenzanthrone	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,3-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1,6-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.20±0.28
1,8-dinitropyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.06±0.09
6a+1e-nitrobenzpyrene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
1-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	N/A±N/A	0.00±0.00	N/A±N/A
3-nitrobenzo[e]pryene	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Table D33: Gas-phase PAH emissions during regeneration emissions testing for Vehicle #1 and Vehicle #3 over the HWFET

Component (ng/mile)	**Vehicle #1**			**Vehicle #3**		
	Baseline HWFET	Federal ULSD	Fed/SME-20	Baseline HWFET	Federal ULSD	Fed/SME-20
Naphthalene	160.83	141.29 ± 199.82	796.09 ± 118.76	1148.59	709.91 ± 110.93	2201.62 ± 423.07
Quinoline	0.00	2.98 ± 4.22	2.20 ± 0.08	0.00	12.03 ± 11.92	4.41 ± 6.23
2-methylnaphthalene	55.10	131.07 ± 21.65	280.08 ± 7.55	213.19	178.93 ± 118.41	437.46 ± 279.80
1-methylnaphthalene	45.31	77.09 ± 21.04	138.49 ± 12.92	115.81	76.26 ± 64.19	240.79 ± 180.21
Biphenyl	12.59	137.23 ± 31.80	196.52 ± 111.16	110.54	386.43 ± 102.57	401.33 ± 305.22

2-methylbiphenyl	9048.16	4946.48 ± 1990.22	3837.52 ± 47.35	9989.33	8845.36 ± 3338.79	12814.00 ± 5523.52
2,6+2,7-dimethylnaphthalene	0.00	0.00 ± 0.00	114.63 ± 31.51	115.81	94.66 ± 53.81	144.98 ± 103.01
1,3+1,6+1,7dimethylnaphth	0.00	11.98 ± 16.95	189.92 ± 33.32	201.08	161.70 ± 132.61	259.93 ± 183.95
1,4+1,5+2,3-dimethylnaphth	6.15	14.39 ± 20.35	65.95 ± 33.21	51.06	55.31 ± 36.74	76.11 ± 51.52
Acenaphthylene	0.00	2.55 ± 3.61	3.22 ± 4.55	7.90	4.15 ± 5.86	3.89 ± 5.50
1,2-dimethylnaphthalene	0.00	4.74 ± 6.70	12.92 ± 15.08	15.79	10.87 ± 8.09	10.37 ± 14.67
1,8-dimethylnaphthalene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthene	0.00	11.79 ± 11.62	20.89 ± 8.15	0.00	4.70 ± 6.65	30.34 ± 42.91
3-methylbiphenyl	2195.61	702.07 ± 992.88	1218.04 ± 70.68	5375.51	3802.33 ± 1348.48	6321.97 ± 2873.64
4-methylbiphenyl	1149.55	396.53 ± 243.45	634.69 ± 137.64	2279.27	1844.64 ± 622.45	3073.37 ± 1089.95
1+2ethylnaphthalene	192.15	174.62 ± 54.39	242.55 ± 15.12	30.00	36.34 ± 24.46	19.97 ± 28.24
1-ethyl-2-methylnaphthalene	4.75	6.49 ± 9.18	36.20 ± 29.81	260.56	249.82 ± 28.77	338.41 ± 86.19
2,3,5+I-trimethylnaphthalene	0.00	0.00 ± 0.00	140.66 ± 68.33	50.01	26.98 ± 12.68	62.14 ± 47.80
B-trimethylnaphthalene	0.00	0.00 ± 0.00	120.61 ± 102.31	101.07	69.23 ± 60.06	76.12 ± 55.18
A-trimethylnaphthalene	1.40	0.00 ± 0.00	148.99 ± 94.66	106.33	66.46 ± 56.15	114.96 ± 88.25
C-trimethylnaphthalene	2.80	0.00 ± 0.00	130.65 ± 66.46	95.80	79.52 ± 45.51	81.29 ± 55.20
2-ethyl-1-methylnaphthalene	0.00	0.00 ± 0.00	7.02 ± 6.90	6.32	44.79 ± 63.34	0.00 ± 0.00
E-trimethylnaphthalene	0.00	2.63 ± 3.72	68.35 ± 39.78	44.74	29.74 ± 16.59	56.96 ± 40.47
2,4,5-trimethylnaphthalene	7.55	2.98 ± 4.22	3.73 ± 2.09	0.00	17.56 ± 19.74	32.14 ± 40.36
F-trimethylnaphthalene	0.00	0.00 ± 0.00	65.64 ± 50.97	45.80	33.38 ± 13.00	52.82 ± 40.45
Fluorene	70.48	38.97 ± 55.11	216.84 ± 19.06	55.27	81.31 ± 53.14	207.14 ± 158.12
1,4,5-trimethylnaphthalene	0.00	1.76 ± 2.48	6.20 ± 4.22	6.32	6.21 ± 7.22	14.00 ± 18.34
J-trimethylnaphthalene	0.00	0.00 ± 0.00	14.17 ± 2.71	1.05	6.41 ± 0.33	1.03 ± 0.00
A-Methylfluorene	10.35	8.25 ± 11.67	46.92 ± 44.97	0.00	2.76 ± 3.91	5.19 ± 7.33
B-Methylfluorene	0.00	5.66 ± 4.40	7.93 ± 4.71	3.68	0.00 ± 0.00	4.41 ± 6.23
1-Methylfluorene	0.00	0.86 ± 0.22	22.30 ± 16.98	5.26	2.76 ± 3.91	2.59 ± 3.67
9-fluorenone	55.10	193.63 ± 131.76	4.34 ± 6.14	52.64	305.59 ± 68.30	282.21 ± 209.64
Dibenzothiophene	0.00	0.35 ± 0.50	2.24 ± 2.30	0.00	5.43 ± 4.05	3.89 ± 5.50
Phenanthrene	46.15	204.23 ± 76.06	388.59 ± 33.04	74.75	175.98 ± 65.49	166.64 ± 81.18
Anthracene	0.00	4.37 ± 4.74	21.00 ± 1.49	5.26	5.53 ± 7.82	0.00 ± 0.00

Xanthone	51.74	2411.82 ± 1481.61	1210.37 ± 479.41	7.90	70.06 ± 29.95	42.79 ± 60.51
1,4-Naphthoquinone	2.80	1.76 ± 2.48	7.73 ± 6.39	8.95	11.84 ± 4.37	3.62 ± 0.02
Acenaphthenequinone	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylphenanthrene	1.40	10.93 ± 11.85	74.94 ± 21.80	15.79	26.88 ± 8.90	12.93 ± 3.71
2-methylphenanthrene	0.56	11.39 ± 14.67	88.17 ± 19.12	31.58	40.51 ± 20.91	15.53 ± 7.38
Perinaphthenone	41.12	81.17 ± 37.62	13.15 ± 1.76	0.00	6.08 ± 8.60	6.20 ± 0.03
2-methylanthracene	0.00	2.15 ± 0.56	9.38 ± 1.89	0.00	2.76 ± 3.91	0.00 ± 0.00
4,5-methylenephenanthrene	0.00	7.02 ± 9.93	9.34 ± 4.11	8.95	4.70 ± 6.65	1.82 ± 2.57
9-methylphenanthrene	0.00	15.70 ± 13.54	44.51 ± 2.89	5.26	27.07 ± 16.45	12.95 ± 11.03
1-methylphenanthrene	1.96	13.54 ± 14.11	24.49 ± 18.61	7.90	40.61 ± 24.68	18.11 ± 7.39
Anthrone	5.59	8.78 ± 12.41	7.81 ± 1.95	22.11	3.83 ± 3.96	8.80 ± 3.70
9-methylanthracene	1.96	3.01 ± 0.79	3.81 ± 2.35	3.68	3.74 ± 0.19	1.82 ± 2.57
Anthraquinone	5.59	21.86 ± 23.70	39.22 ± 0.85	0.00	24.31 ± 12.54	2.59 ± 3.67
A-dimethylphenanthrene	1.96	1.23 ± 1.74	8.48 ± 0.30	0.00	1.38 ± 1.95	0.00 ± 0.00
B-dimethylphenanthrene	0.56	2.11 ± 2.98	8.36 ± 6.37	18.42	21.45 ± 4.86	25.82 ± 10.85
1,7-dimethylphenanthrene	1.96	3.01 ± 0.79	11.70 ± 4.85	6.32	14.70 ± 12.06	1.03 ± 0.00
3,6-dimethylphenanthrene	2.80	1.76 ± 2.48	3.14 ± 0.11	0.00	2.67 ± 0.14	1.30 ± 1.83
D-dimethylphenanthrene	0.00	5.66 ± 4.40	12.52 ± 1.78	0.00	4.15 ± 5.86	1.30 ± 1.83
E-dimethylphenanthrene	0.00	9.57 ± 6.32	3.14 ± 0.11	1.05	1.07 ± 0.05	0.52 ± 0.73
C-dimethylphenanthrene	0.56	59.25 ± 46.28	29.12 ± 14.33	6.32	11.93 ± 8.15	6.20 ± 0.03
Fluoranthene	9.79	42.36 ± 41.87	48.83 ± 10.58	16.84	55.02 ± 25.41	5.70 ± 8.07
Pyrene	25.17	149.38 ± 77.22	78.74 ± 16.06	3.68	32.35 ± 45.75	4.41 ± 6.23
9-Anthraaldehyde	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	21.35 ± 1.09	5.19 ± 7.33
Retene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
benzo(a)fluorene	0.00	0.00 ± 0.00	1.61 ± 2.28	0.00	2.76 ± 3.91	0.00 ± 0.00
benzo(b)fluorene	0.00	1.76 ± 2.48	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
5-methylchrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
B-MePy/MeFl	0.00	0.00 ± 0.00	1.13 ± 1.59	0.00	0.00 ± 0.00	0.00 ± 0.00
1-MeFl+C-MeFl/Py	0.00	1.23 ± 1.74	0.00 ± 0.00	0.00	5.34 ± 0.27	2.59 ± 3.67
1+3-methylfluoranthene	0.00	1.23 ± 1.74	1.13 ± 1.59	2.63	1.38 ± 1.95	0.00 ± 0.00

4-methylpyrene	0.00	1.23 ± 1.74	3.73 ± 2.09	3.68	0.00 ± 0.00	0.00 ± 0.00
C-MePy/MeFl	0.00	2.98 ± 4.22	1.07 ± 1.52	0.00	1.80 ± 2.55	0.00 ± 0.00
D-MePy/MeFl	0.00	1.23 ± 1.74	1.13 ± 1.59	0.00	1.94 ± 2.74	0.00 ± 0.00
1-methylpyrene	1.40	1.27 ± 1.80	3.10 ± 2.11	0.00	5.34 ± 0.27	0.00 ± 0.00
Benzonaphthothiophene	0.00	0.86 ± 0.22	0.32 ± 0.46	1.05	0.00 ± 0.00	0.00 ± 0.00
benzo(c)phenanthrene	1.40	0.00 ± 0.00	2.30 ± 3.25	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(ghi)fluoranthene	0.00	2.15 ± 0.56	0.77 ± 1.08	3.68	4.37 ± 6.19	0.00 ± 0.00
9-phenylanthracene	0.00	4.31 ± 1.12	0.00 ± 0.00	0.00	2.76 ± 3.91	0.00 ± 0.00
6-methylchrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00	3.01 ± 0.79	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benz(a)anthracene	0.00	1.23 ± 1.74	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Chrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzanthrone	0.00	4.31 ± 1.12	1.61 ± 2.28	0.00	0.55 ± 0.78	0.52 ± 0.73
Benz(a)anthracene-7,12-dione	2.80	6.06 ± 1.36	1.61 ± 2.28	0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylchrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenz(a)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
7,12-dimethylbenz(a)anthracene	0.00	57.55 ± 26.79	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(j)fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(k)fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(a)fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
BeP	0.00	1.78 ± 2.52	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
BaP	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Perylene	1.40	1.27 ± 1.80	0.80 ± 1.14	0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylcholanthrene	0.56	5.96 ± 7.44	0.63 ± 0.02	5.26	5.15 ± 7.28	2.58 ± 3.64
7-methylbenzo(a)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	2.57 ± 3.64	0.00 ± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	1.96	4.77 ± 1.70	1.13 ± 1.59	0.00	2.57 ± 3.64	0.00 ± 0.00
Indeno[123-cd]fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ac)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00

Dibenzo(ah+ac)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00	33.94 ± 14.74	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Picene	0.00	0.00 ± 0.00	0.00 ± 0.00	1.05	0.51 ± 0.73	0.52 ± 0.73
Benzo(ghi)perylene	0.00	1.78 ± 2.52	1.07 ± 1.52	1.05	0.55 ± 0.78	0.52 ± 0.73
Anthanthrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Triphenylene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,l)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,e)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00

Table D34: Particle-phase PAH emissions during regeneration emissions testing for Vehicle #1 and Vehicle #3 over the HWFET

Component (ng/mile)	**Vehicle #1**			**Vehicle #3**		
	Baseline HWFET	Federal ULSD	Fed/SME-20	Baseline HWFET	Federal ULSD	Fed/SME-20
Naphthalene	27.13	20.24 ± 0.40	0.00 ± 0.00	0.00	5.76 ± 1.75	39.85 ± 17.16
Quinoline	0.00	7.79 ± 11.01	7.14 ± 1.52	0.00	3.00 ± 4.24	7.06 ± 9.20
2-methylnaphthalene	42.75	29.55 ± 10.84	0.00 ± 0.00	0.00	13.95 ± 0.58	22.01 ± 14.10
1-methylnaphthalene	18.76	17.83 ± 3.18	4.62 ± 3.85	0.00	0.10 ± 0.14	9.81 ± 5.90
Biphenyl	2.02	1.85 ± 2.62	0.74 ± 0.60	0.00	0.36 ± 0.51	5.00 ± 5.74
2-methylbiphenyl	3.23	9.46 ± 11.47	12.20 ± 5.60	0.00	0.00 ± 0.00	0.00 ± 0.00
2,6+2,7-dimethylnaphthalene	9.10	4.76 ± 5.21	1.54 ± 0.14	0.00	4.56 ± 0.16	4.75 ± 2.03
1,3+1,6+1,7dimethylnaphth	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,4+1,5+2,3-dimethylnaphth	0.00	2.39 ± 3.39	0.00 ± 0.00	18.58	13.88 ± 19.63	34.68 ± 3.60
Acenaphthylene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,2-dimethylnaphthalene	3.36	2.20 ± 1.27	0.66 ± 0.94	0.00	7.37 ± 3.79	3.45 ± 1.33

1,8-dimethylnaphthalene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	2.20 ± 3.12	0.98 ± 1.38
Acenaphthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylbiphenyl	0.00	0.00 ± 0.00	4.75 ± 4.04	0.00	35.13 ± 0.91	12.74 ± 18.02
4-methylbiphenyl	0.00	1.44 ± 2.03	1.85 ± 1.93	0.00	20.40 ± 1.44	4.49 ± 6.34
1+2ethylnaphthalene	41.37	19.17 ± 27.12	52.68 ± 5.13	0.00	0.00 ± 0.00	0.00 ± 0.00
1-ethyl-2-methylnaphthalene	0.00	0.00 ± 0.00	2.36 ± 0.41	0.00	0.00 ± 0.00	0.00 ± 0.00
2,3,5+I-trimethylnaphthalene	0.00	3.13 ± 4.43	2.88 ± 0.38	0.00	0.00 ± 0.00	0.00 ± 0.00
B-trimethylnaphthalene	5.98	10.51 ± 8.55	5.81 ± 0.88	0.90	5.59 ± 2.92	1.95 ± 0.25
A-trimethylnaphthalene	0.00	0.00 ± 0.00	0.75 ± 0.24	0.00	4.75 ± 1.05	0.48 ± 0.26
C-trimethylnaphthalene	0.94	0.70 ± 0.99	0.18 ± 0.25	0.00	0.00 ± 0.00	0.00 ± 0.00
2-ethyl-1-methylnaphthalene	0.00	0.00 ± 0.00	6.10 ± 7.35	2.08	0.72 ± 1.02	0.00 ± 0.00
E-trimethylnaphthalene	0.00	0.00 ± 0.00	4.09 ± 2.57	0.00	0.00 ± 0.00	0.00 ± 0.00
2,4,5-trimethylnaphthalene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	4.24 ± 0.45	0.45 ± 0.36
F-trimethylnaphthalene	2.92	1.77 ± 2.51	1.04 ± 1.47	0.00	0.00 ± 0.00	0.00 ± 0.00
Fluorene	0.00	0.00 ± 0.00	0.00 ± 0.00	2.75	0.79 ± 0.85	1.21 ± 1.04
1,4,5-trimethylnaphthalene	2.10	0.00 ± 0.00	8.15 ± 2.94	5.96	29.32 ± 7.11	7.88 ± 7.55
J-trimethylnaphthalene	0.00	0.00 ± 0.00	1.58 ± 2.23	0.00	0.00 ± 0.00	0.00 ± 0.00
A-Methylfluorene	0.00	1.80 ± 2.55	0.90 ± 0.68	4.73	3.31 ± 2.48	4.54 ± 1.06
B-Methylfluorene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.98 ± 1.39
1-Methylfluorene	0.00	0.00 ± 0.00	1.92 ± 2.17	1.46	3.58 ± 0.63	0.00 ± 0.00
9-fluorenone	0.00	17.40 ± 3.13	10.13 ± 0.51	1.19	5.72 ± 1.38	28.20 ± 1.39
Dibenzothiophene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Phenanthrene	0.72	11.28 ± 3.43	14.27 ± 2.27	0.12	9.30 ± 0.64	27.08 ± 16.71
Anthracene	0.00	0.00 ± 0.00	0.93 ± 0.60	1.19	1.18 ± 1.56	4.92 ± 3.53
Xanthone	13.28	985.26 ± 337.47	209.50 ± 13.43	8.40	9.30 ± 2.93	8.95 ± 0.27
1,4-Naphthoquinone	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Acenaphthenequinone	0.00	0.00 ± 0.00	0.00 ± 0.00	8.60	1.92 ± 1.71	6.18 ± 3.56
3-methylphenanthrene	0.00	0.13 ± 0.19	3.85 ± 0.19	2.69	3.31 ± 0.27	7.92 ± 3.15
2-methylphenanthrene	0.53	2.55 ± 3.61	11.07 ± 4.89	3.19	4.82 ± 0.78	9.96 ± 4.24
Perinaphthenone	8.43	0.00 ± 0.00	17.71 ± 0.79	0.00	40.47 ± 24.62	0.00 ± 0.00

2-methylanthracene	0.00	0.00 ± 0.00	0.13 ± 0.19	0.00	0.00 ± 0.00	5.27 ± 6.90
4,5-methylenephenanthrene	0.00	0.00 ± 0.00	0.00 ± 0.00	5.40	4.74 ± 0.74	3.64 ± 1.04
9-methylphenanthrene	0.00	0.00 ± 0.00	3.94 ± 0.68	0.61	2.85 ± 1.94	3.87 ± 1.71
1-methylphenanthrene	0.00	3.24 ± 4.59	6.12 ± 2.15	1.01	2.49 ± 1.83	4.86 ± 1.29
Anthrone	0.00	0.00 ± 0.00	0.00 ± 0.00	12.93	9.28 ± 13.13	0.00 ± 0.00
9-methylanthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Anthraquinone	2.33	31.45 ± 0.02	20.21 ± 0.98	0.00	0.00 ± 0.00	10.76 ± 9.82
A-dimethylphenanthrene	0.00	0.00 ± 0.00	0.00 ± 0.00	3.78	3.30 ± 2.06	7.42 ± 2.27
B-dimethylphenanthrene	0.00	0.00 ± 0.00	5.59 ± 1.02	2.38	1.56 ± 0.60	3.63 ± 1.04
1,7-dimethylphenanthrene	0.00	0.00 ± 0.00	1.47 ± 2.08	1.00	3.49 ± 0.20	6.61 ± 1.23
3,6-dimethylphenanthrene	0.00	0.00 ± 0.00	0.68 ± 0.45	2.08	0.30 ± 0.42	4.91 ± 0.30
D-dimethylphenanthrene	3.26	0.00 ± 0.00	4.71 ± 0.97	2.22	6.21 ± 0.70	7.70 ± 1.39
E-dimethylphenanthrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.46 ± 0.64
C-dimethylphenanthrene	0.00	0.00 ± 0.00	4.94 ± 0.77	5.75	6.59 ± 0.86	7.09 ± 10.03
Fluoranthene	0.00	17.58 ± 5.74	6.86 ± 4.24	1.96	10.04 ± 0.55	38.14 ± 9.17
Pyrene	0.00	27.89 ± 12.16	15.99 ± 6.63	0.00	3.15 ± 4.46	54.73 ± 18.86
9-Anthraaldehyde	0.00	0.00 ± 0.00	2.41 ± 3.41	0.00	0.00 ± 0.00	0.00 ± 0.00
Retene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.08 ± 0.11	0.00 ± 0.00
benzo(a)fluorene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.27 ± 0.38	0.88 ± 1.25
benzo(b)fluorene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.41 ± 0.58	0.79 ± 0.36
5-methylchrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
B-MePy/MeFl	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	2.84 ± 1.93	1.21 ± 1.71
1-MeFl+C-MeFl/Py	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	1.08 ± 1.53
1+3-methylfluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	2.17 ± 3.07
4-methylpyrene	0.00	7.80 ± 3.44	6.92 ± 2.58	1.04	1.15 ± 1.62	4.03 ± 0.63
C-MePy/MeFl	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
D-MePy/MeFl	0.00	0.00 ± 0.00	5.38 ± 0.44	2.51	3.28 ± 2.32	5.69 ± 1.02
1-methylpyrene	0.00	1.13 ± 1.60	4.22 ± 0.41	0.62	0.23 ± 0.33	3.41 ± 0.98
Benzonaphthothiophene	0.00	0.00 ± 0.00	0.00 ± 0.00	1.88	0.58 ± 0.27	4.29 ± 0.96
benzo(c)phenanthrene	0.00	0.00 ± 0.00	0.90 ± 1.28	0.00	2.27 ± 1.46	2.13 ± 3.01

Benzo(ghi)fluoranthene	0.00	23.56 ± 12.17	30.24 ± 15.65	3.30	17.68 ± 6.71	41.38 ± 27.84
9-phenylanthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	1.39 ± 1.97
6-methylchrysene	0.00	0.00 ± 0.00	0.74 ± 1.04	0.00	0.40 ± 0.56	0.00 ± 0.00
Cyclopenta(c,d)pyrene	0.00	0.00 ± 0.00	2.03 ± 0.29	0.00	0.85 ± 0.04	1.13 ± 0.57
Benz(a)anthracene	0.00	0.00 ± 0.00	4.15 ± 1.46	1.71	1.61 ± 1.85	13.42 ± 10.06
Chrysene	0.00	3.00 ± 4.24	11.46 ± 5.61	3.60	8.64 ± 3.39	21.42 ± 13.46
Benzanthrone	0.00	0.00 ± 0.00	21.45 ± 12.86	3.61	8.29 ± 3.53	22.99 ± 17.52
Benz(a)anthracene-7,12-dione	0.00	0.00 ± 0.00	7.29 ± 5.01	0.00	2.88 ± 4.08	9.80 ± 6.18
3-methylchrysene	0.00	0.00 ± 0.00	0.95 ± 1.34	0.00	0.00 ± 0.00	1.68 ± 1.32
7-methylbenz(a)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.49 ± 0.69	0.00 ± 0.00
7,12-dimethylbenz(a)anthracene	4.49	6.70 ± 2.95	3.43 ± 0.23	1.16	3.61 ± 0.80	2.68 ± 3.79
Benzo(b)fluoranthene	0.00	1.98 ± 0.26	11.43 ± 8.04	2.52	5.83 ± 2.41	30.20 ± 24.34
Benzo(j)fluoranthene	0.00	0.00 ± 0.00	3.83 ± 2.74	0.62	1.46 ± 1.48	11.70 ± 9.91
Benzo(k)fluoranthene	0.00	0.00 ± 0.00	2.44 ± 1.35	0.21	0.55 ± 0.70	8.23 ± 7.62
Benzo(a)fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.90 ± 0.77
BeP	0.49	0.99 ± 0.30	6.32 ± 4.20	1.49	2.75 ± 2.27	17.60 ± 14.00
BaP	0.00	0.00 ± 0.00	0.12 ± 0.17	0.53	0.00 ± 0.00	4.27 ± 4.25
Perylene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
3-methylcholanthrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
7-methylbenzo(a)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
9,10-dihydrobenzo(a)pyrene-7(8H)-one	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Indeno[123-cd]fluoranthene	0.00	0.00 ± 0.00	1.38 ± 0.51	0.00	0.00 ± 0.00	1.13 ± 1.60
Indeno[123-cd]pyrene	0.00	0.00 ± 0.00	1.53 ± 0.70	1.36	0.36 ± 0.50	9.85 ± 8.52
Dibenzo(ac)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah+ac)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(ah)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,j)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Benzo(b)chrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Picene	0.00	0.00 ± 0.00	4.33 ± 1.24	0.18	0.95 ± 1.35	0.00 ± 0.00
Benzo(ghi)perylene	0.00	0.00 ± 0.00	4.77 ± 2.38	2.83	1.03 ± 1.45	32.74 ± 27.84

Anthanthrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Triphenylene	0.00	2.45 ± 3.47	2.11 ± 2.98	0.99	4.00 ± 0.75	5.05 ± 2.09
Dibenzo(a,l)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Coronene	0.00	0.00 ± 0.00	0.00 ± 0.00	2.92	0.00 ± 0.00	30.43 ± 27.09
Dibenzo(a,e)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,i)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(a,h)pyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
Dibenzo(b,k)fluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00

Table D35: Gas-phase nitro-PAH emissions during regeneration emissions testing for Vehicle #1 and Vehicle #3 over the HWFET

Compound (ng/mile)	**Vehicle #1**			**Vehicle #3**		
	Baseline HWFET	Federal ULSD	Fed/SME-20	Baseline HWFET	Federal ULSD	Fed/SME-20
1-nitronaphthalene	14.56	13.90 ± 2.52	0.00 ± 0.00	25.35	25.55 ± 1.74	24.13 ± 34.12
1-methyl-5-nitronaphthalene	0.04	0.00 ± 0.00	0.72 ± 0.20	0.08	0.13 ± 0.04	0.47 ± 0.31
2-nitronaphthalene	0.14	2.22 ± 0.37	6.05 ± 0.10	0.45	1.21 ± 0.59	3.21 ± 2.15
2-nitrobiphenyl	0.27	0.63 ± 0.07	0.60 ± 0.05	0.61	0.88 ± 0.01	0.94 ± 0.37
2-methyl-4-nitronaphthalene	0.00	0.05 ± 0.07	0.84 ± 0.32	0.00	0.00 ± 0.00	0.64 ± 0.90
1-methyl-4-nitronaphthalene	0.06	0.07 ± 0.10	0.87 ± 0.22	0.00	0.00 ± 0.00	0.68 ± 0.79
1-methyl-6-nitronaphthalene	0.00	2.29 ± 1.71	3.60 ± 0.02	1.10	0.71 ± 1.01	6.67 ± 9.43
3-nitrobiphenyl	0.05	0.32 ± 0.18	0.52 ± 0.14	0.10	0.46 ± 0.07	0.47 ± 0.14
4-nitrobiphenyl	0.00	0.33 ± 0.46	0.54 ± 0.09	0.00	3.10 ± 0.77	2.99 ± 1.11
1,3-dinitronaphthalene	0.00	3.49 ± 3.30	3.33 ± 1.41	0.00	0.00 ± 0.00	0.54 ± 0.77
1,5-dinitronaphthalene	0.06	5.13 ± 5.00	2.73 ± 1.34	0.00	0.00 ± 0.00	0.10 ± 0.14
5-nitroacenaphthene	0.09	0.16 ± 0.03	0.04 ± 0.06	0.06	0.13 ± 0.18	0.03 ± 0.04
2-nitrofluorene	0.00	0.02 ± 0.03	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
4-nitrophenanthrene	38.82	2.07 ± 2.93	0.82 ± 1.01	0.00	0.00 ± 0.00	1.06 ± 1.49
9-nitroanthracene	0.00	0.90 ± 1.28	1.93 ± 0.04	0.00	0.81 ± 0.00	3.10 ± 4.39
9-nitrophenanthrene	0.19	1.08 ± 1.28	1.88 ± 0.75	0.00	0.12 ± 0.08	1.68 ± 1.35
1,8-dinitronaphthalene	0.00	0.02 ± 0.03	0.05 ± 0.08	0.00	0.00 ± 0.00	0.00 ± 0.00

3-nitrophenanthrene	70.49	37.98 ± 10.51	8.07 ± 3.46	1.10	7.98 ± 11.28	5.83 ± 4.17
2-nitrophenanthrene	0.00	0.44 ± 0.35	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
2-nitroanthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
2-nitrofluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
3-nitrofluoranthene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
4-nitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1-nitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
2-nitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
2,7-dinitrofluorene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
2,7-dinitrofluoren-9-one	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
7-nitrobenz(a)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
6-nitrochrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
3-nitrobenzanthrone	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,3-dinitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,6-dinitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,8-dinitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
6a+1e-nitrobenzpyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1-nitrobenzo[e]pryene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
3-nitrobenzo[e]pryene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00

Table D36: Particle-phase nitro-PAH emissions during regeneration emissions testing for Vehicle #1 and Vehicle #3 over the HWFET

Compound (ng/mile)	**Vehicle #1**			**Vehicle #3**		
	Baseline HWFET	Federal ULSD	Fed/SME-20	Baseline HWFET	Federal ULSD	Fed/SME-20
1-nitronaphthalene	0.00	0.06 ± 0.02	0.04 ± 0.01	0.00	0.03 ± 0.00	0.06 ± 0.02
1-methyl-5-nitronaphthalene	0.00	0.00 ± 0.00	0.01 ± 0.00	0.00	0.00 ± 0.00	0.01 ± 0.01
2-nitronaphthalene	0.01	0.11 ± 0.01	0.10 ± 0.00	0.02	0.05 ± 0.03	0.11 ± 0.03
2-nitrobiphenyl	0.00	0.02 ± 0.01	0.03 ± 0.02	0.00	0.02 ± 0.02	0.02 ± 0.02
2-methyl-4-nitronaphthalene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.01	0.06 ± 0.06	0.00 ± 0.00
1-methyl-4-nitronaphthalene	0.00	0.10 ± 0.13	0.05 ± 0.07	0.00	0.00 ± 0.00	0.10 ± 0.09

1-methyl-6-nitronaphthalene	0.08	0.00 ± 0.00	0.00 ± 0.00	0.04	0.00 ± 0.00	0.00 ± 0.00
3-nitrobiphenyl	0.00	0.03 ± 0.00	0.02 ± 0.00	0.01	0.01 ± 0.01	0.05 ± 0.00
4-nitrobiphenyl	0.00	0.93 ± 0.58	0.82 ± 0.01	0.00	0.03 ± 0.04	0.27 ± 0.15
1,3-dinitronaphthalene	0.19	3.13 ± 1.59	0.88 ± 0.22	0.00	0.00 ± 0.00	0.00 ± 0.00
1,5-dinitronaphthalene	0.00	1.30 ± 0.86	0.46 ± 0.17	0.00	0.00 ± 0.00	0.01 ± 0.02
5-nitroacenaphthene	0.10	0.00 ± 0.00	0.02 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
2-nitrofluorene	0.00	1.06 ± 1.49	0.76 ± 0.19	0.00	0.00 ± 0.00	0.00 ± 0.00
4-nitrophenanthrene	0.11	2.57 ± 1.02	0.88 ± 0.28	0.04	0.16 ± 0.01	0.28 ± 0.15
9-nitroanthracene	0.01	0.27 ± 0.12	0.07 ± 0.02	0.05	0.23 ± 0.07	0.55 ± 0.05
9-nitrophenanthrene	1.04	7.99 ± 7.09	4.80 ± 2.42	0.00	0.00 ± 0.00	0.00 ± 0.00
1,8-dinitronaphthalene	0.03	1.25 ± 0.52	0.53 ± 0.28	0.03	0.16 ± 0.05	0.24 ± 0.03
3-nitrophenanthrene	0.51	7.74 ± 6.71	4.27 ± 1.94	0.15	1.58 ± 0.72	2.03 ± 0.90
2-nitrophenanthrene	0.00	1.01 ± 0.47	0.75 ± 0.13	0.10	0.42 ± 0.30	0.39 ± 0.00
2-nitroanthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
2-nitrofluoranthene	0.04	0.39 ± 0.24	0.27 ± 0.17	0.00	0.03 ± 0.02	0.02 ± 0.01
3-nitrofluoranthene	0.00	0.04 ± 0.05	0.19 ± 0.26	0.00	0.06 ± 0.01	0.00 ± 0.00
4-nitropyrene	0.01	0.24 ± 0.11	0.37 ± 0.34	0.00	0.07 ± 0.00	0.20 ± 0.28
1-nitropyrene	0.12	1.96 ± 1.81	1.99 ± 1.17	0.12	8.32 ± 5.28	1.91 ± 0.17
2-nitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.04 ± 0.06	2.59 ± 2.74
2,7-dinitrofluorene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.03 ± 0.05	0.00 ± 0.00
2,7-dinitrofluoren-9-one	0.00	0.00 ± 0.00	0.00 ± 0.00	0.02	0.00 ± 0.00	0.00 ± 0.00
7-nitrobenz(a)anthracene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.32 ± 0.07	0.00 ± 0.00
6-nitrochrysene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.06 ± 0.09	0.00 ± 0.00
3-nitrobenzanthrone	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,3-dinitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,6-dinitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1,8-dinitropyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	1.81 ± 2.56
6a+1e-nitrobenzpyrene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
1-nitrobenzo[e]pryene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00
3-nitrobenzo[e]pryene	0.00	0.00 ± 0.00	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00 ± 0.00