

Particulate Measurements and Emissions Characterization of Alternative Fuel Vehicle Exhaust

T.D. Durbin, T.J. Truex, and J.M. Norbeck
*Center for Environmental Research and Technology
College of Engineering, University of California
Riverside, California*



National Renewable Energy Laboratory
1617 Cole Boulevard
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NREL technical monitor: P. Bergeron



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Abstract

The objective of this project was to measure and characterize particulate emissions from light-duty alternative fuel vehicles (AFVs) and equivalent gasoline-fueled vehicles. This work is part of a more extensive research program co-sponsored by the Coordinating Research Council, the South Coast Air Quality Management District, and the National Renewable Energy Laboratory (NREL) to augment the current database of particulate emissions from conventional vehicles and light-duty AFVs. It includes particulate emission testing of a fleet of 129 gasoline-fueled vehicles and 19 diesel vehicles (Norbeck, Durbin, and Truex 1998). Particulate measurements were obtained over Federal Test Procedure (FTP) and US06 cycles for total particulate, as well as the fraction of particulate below 1.0, 2.5, and 10.0 μm . Chemical characterization of the exhaust particulate was also performed, including determination of organic and elemental carbon fractions, analysis for trace elements and ions, and speciation of polynuclear aromatic hydrocarbons (PAHs), hopanes, and steranes.

FTP average particulate emissions for compressed natural gas (CNG) and 85% methanol/15% gasoline (M85) fueled vehicles were 1.40 and 0.70 mg/mi, respectively. These values are low and comparable to those of their gasoline counterparts. CNG vehicles produced lower non-methane hydrocarbon (NMHC) and carbon monoxide (CO) emissions than gasoline vehicles for both the FTP and the US06. Oxides of nitrogen (NO_x) emissions for CNG vehicles were comparable to those for the gasoline vehicles for the fleet average, and slightly lower when the highest-emitting CNG vehicle was removed from the average. M85 produced lower NO_x emissions but higher CO and organic material hydrocarbon equivalent (OMHCE) emissions than did reformulated gasoline (RFG) over the FTP. M85 produced lower emissions than RFG for total hydrocarbons (THC), NMHC, CO, and NO_x over the US06 cycle. Particulate, NO_x and CO emissions were higher from the more aggressive US06 cycle than from the FTP for all vehicle/fuel combinations, with some vehicles having significant increases in particulate emissions over the US06. Average US06 particulate emissions were 7.76 and 3.62 mg/mi, respectively, for the CNG and M85 vehicles, or a factor of more than 5 greater than the FTP values. Most of the particulate mass was below 10 μm in aerodynamic diameter (77%-92%) with 58%-82% of the mass below 2.5 μm , and 42%-77% below 1.0 μm .

Particulate samples were analyzed for organic and elemental carbon, trace elements and ions. Elemental and organic carbon were primary constituents. Other species identified include possible fuel-derived components (SO_4^{2-} , S) and oil/wear derived components (Mg, P, Ca, Zn, Fe, Si, and Al). Low emissions levels and large sample-to-sample variability made it difficult to differentiate between the species profiles for different vehicle/fuel combinations. PAH emissions were highest for the RFG vehicles over the FTP and the US06. PAH emissions for M85 vehicles were considerably lower than RFG over the US06; PAH emissions for CNG vehicles were considerably lower than those for RFG vehicles over both the FTP and US06.

Glossary and Abbreviations

ACNAPE	acenaphthene
ACNAPY	acenaphthylene
AFV	alternative fuel vehicle
A_MFLU	a-methylfluorene
ANTHRA	anthracene
ATMNAP	a-trimethylnaphthalene
A_MPHT	a-methylphenanthrene
BBJKFL	benzo(b+j+k)fluoranthene
BIPHEN	biphenyl
BTMNAP	b-trimethylnaphthalene
C_DMPH	c-dimethylphenanthrene
CE-CERT	College of Engineering: Center for Environmental Research and Technology
C_MFLU	c-methylfluorene
C_MPYR	c-methylpyrene
CNG	compressed natural gas
CO	carbon monoxide
CTMNAP	c-trimethylnaphthalene
CVS	constant volume sampler
D14523	2,3+1,4+1,5-dimethylnaphthalene
DMN12	1,2-dimethylnaphthalene
DMN267	2,6+2,7-dimethylnaphthalene
DMN1367	1,7+1,3+1,6-dimethylnaphthalene
DNPH	dinitrophenyl-hydrazine
DRI	Desert Research Institute
EI	electron impact
EM_12N	1-ethyl-2-methylnaphthalene
ETMNAP	e-trimethylnaphthalene
FFV	flexible-fuel vehicle
FLUORA	fluoranthene
FLUORE	fluorene
FTMNAP	f-trimethylnaphthalene
FTP	Federal Test Procedure
GC/MS	gas chromatography/mass spectrometry
GTMNAP	g-trimethylnaphthalene
HPLC	high-performance liquid chromatography
lpm	liters per minute
M-1FLU	1-methylfluorene
M_1PHT	1-methylphenanthrene
M_2BPH	2-methylbiphenyl

M_2PHT.....	2-methylphenanthrene
M_3BPH.....	3-methylbiphenyl
M_4BPH.....	4-methylbiphenyl
M85.....	85% methanol/15% gasoline fuel
MNAPH1	1-methylnaphthalene
MNAPH2	2-methylnaphthalene
NAPHTH.....	naphthalene
NMHC.....	non-methane hydrocarbons
NO _x	oxides of nitrogen
OC.....	oxidation catalyst
OMHCE	organic material hydrocarbon equivalent
PAH.....	polynuclear aromatic hydrocarbons
PHENAN.....	phenanthrene
PM.....	particulates
PTFE.....	polytetrafluoroethylene
PUF	polyurethane foam plugs used for measuring semi-volatile organic compounds
PYRENE.....	pyrene
RFG.....	California Phase II reformulated gasoline
scfm.....	standard cubic feet per minute
TOR.....	Thermal/Optical Reflectance analysis
THC.....	total hydrocarbons
TWC.....	three-way catalyst
VERL.....	Vehicle Emission Research Laboratory
XAD	polymer resin used for measuring semi-volatile organic compounds
XRF	x-ray fluorescence

1.0 Introduction

Although significant improvements in air quality have been made over the past 20 years, many parts of the country still do not comply with National Ambient Air Quality Standards (NAAQS). To help address this problem, Congress enacted the Clean Air Act Amendments of 1990, with provisions to force broad changes in fuels and vehicles. As the transportation industry struggles to comply with these regulations, alternative fuels and reformulated gasolines have emerged as important components of many air pollution reduction plans. Alternative fuels, in particular, offer the potential dual benefits of energy independence and an improvement in air quality. For alternative fuels to be viable replacements for their petroleum-based counterparts, however, their impact on air quality must be assessed. Although much research has shown potential air quality benefits from alternative transportation fuels, many uncertainties still exist in the technical community about the impacts of alternative fuels, and the emissions rates and composition of some combustion products.

One pollutant that has received considerable attention recently is particulate matter. Recent studies indicate that increases in human mortality and morbidity are associated with particulate (PM) pollution levels significantly lower than those previously believed to affect human health (Dockery and Pope, 1994; Health Effects Institute, 1995). Limited studies have shown that particulate emission rates from properly functioning modern gasoline-fueled vehicles are small: on the order of 2-10 mg/mi (Hammerle et al., 1991; Siegel et al., 1994; Zinbo, Karniski, and Weir, 1995). Several recent studies have shown, however, that high carbon monoxide (CO) emitting and smoking vehicles can have particulate emission rates several orders of magnitude higher than properly functioning modern gasoline-fueled vehicles (Dickson, Henning, and Oliver, 1991; Sagebiel et al., 1997; Cadle et al., 1997; Durbin et al., 1999).

The objective of this project was to measure particulate emissions from light-duty alternative fuel vehicles (AFVs) and equivalent gasoline-fueled vehicles. Particulate measurements were obtained over Federal Test Procedure (FTP) and US06 cycles. Measurements included total particulate as well as the fraction of particulates below 1.0, 2.5, and 10.0 μm . Chemical characterization of the exhaust particulate was also performed, including determination of organic and elemental carbon fractions, analysis for trace elements and ions, and speciation of polynuclear aromatic hydrocarbons (PAHs), hopanes, and steranes. This work is part of a more extensive research program co-sponsored by the Coordinating Research Council, the South Coast Air Quality Management District, and the National Renewable Energy Laboratory to augment the current database of particulate emissions from conventional and alternative fuel light-duty vehicles, and includes particulate emission testing of a fleet of 129 gasoline-fueled vehicles and 19 diesel vehicles (Norbeck, Durbin, and Truex, 1998).

2.0 Experimental Procedures

2.1 Vehicle Fleet Description and Recruitment

Table 1 lists and describes the vehicles tested in this program. For each fuel category, five vehicles with the same make, model, and model year were selected for testing. In conjunction with each AFV tested, control tests also were performed. Control tests were run on California Phase II Reformulated Gasoline (RFG) using the same engine or vehicle for M85, and on vehicles with the same make, model, and model year for the CNG vehicles. To the extent possible, CNG and RFG control vehicles with similar mileages were sought. Although there were some differences in the mileages for the CNG and RFG control vehicles, the effect of mileage on the emissions results is expected to be small in comparison with the effects observed for vehicles operating on different fuel types. Where possible all vehicles within a specific fuel group were obtained from the same fleet operator. The CNG Dodge Caravans were obtained from the University of California, Riverside, fleet services department. The RFG Dodge Caravans were all obtained from VPSI Inc., a commuter van service. The Ford flexible-fuel Tauruses were all obtained from private owners.

Table 1. AFV Testing Matrix

	Model Year	Make	Model	Odometer (miles)	Engine Size/Type	Catalyst Type
CNG Vehicles						
1	1994	Dodge	Caravan	30,793	3.3L V6	TWC+OC
2	1994	Dodge	Caravan	38,154	3.3L V6	TWC+OC
3	1994	Dodge	Caravan	21,321	3.3L V6	TWC+OC
4	1994	Dodge	Caravan	14,117	3.3L V6	TWC+OC
5	1994	Dodge	Caravan	46,765	3.3L V6	TWC+OC
RFG Control Vehicles						
1	1994	Dodge	Caravan	40,834	3.3L V6	TWC
2	1994	Dodge	Caravan	48,478	3.3L V6	TWC
3	1994	Dodge	Caravan	65,335	3.3L V6	TWC
4	1994	Dodge	Caravan	73,354	3.3L V6	TWC
5	1994	Dodge	Caravan	74,379	3.3L V6	TWC
M85 and RFG Control Vehicles (operated on M85 and RFG)						
1	1994	Ford	FFV Taurus	98,328	3.0L V6	TWC
2	1994	Ford	FFV Taurus	31,660	3.0L V6	TWC
3	1994	Ford	FFV Taurus	47,973	3.0L V6	TWC
4	1994	Ford	FFV Taurus	61,499	3.0L V6	TWC
5	1994	Ford	FFV Taurus	51,988	3.0L V6	TWC

2.2 Test Fuels

The three test fuels used for this project were CNG, M85, and RFG. M85 and RFG were both obtained from Phillips Petroleum Company in Borger, Texas. The M85 for testing was produced by splash-blending 85% pure methanol with 15% RFG. The fuel for the CNG vehicles was obtained from

the local campus supply station, which was common to all the CNG test vehicles. Appendix A presents fuel specifications and analyses on fuel samples for the CNG, M85, and RFG.

2.3 Vehicle Testing

Each vehicle/fuel combination was tested for total hydrocarbons (THC), non-methane hydrocarbons (NMHC), CO, oxides of nitrogen (NO_x), and particulate emissions over back-to-back FTPs on consecutive days. Immediately following the completion of the second FTP for each vehicle/fuel combination, each vehicle was tested over 2-4 iterations of the US06 cycle for gaseous and particulate emissions. Four iterations of the US06 were used to collect sufficient particulate samples for chemical analysis. Alcohol and carbonyl emissions were also collected on a subset of the tests on the M85 and RFG vehicles. The details of the particulate and alcohol sampling are presented in Sections 2.4 and 2.6, respectively. All M85 and RFG vehicles were refueled and preconditioned using the procedures developed through Auto/Oil program (Burns et al., 1991). The heat build steps were excluded from the preconditioning because evaporative emissions tests were not conducted. The CNG Dodge Caravans were preconditioned over one iteration of the LA4 driving schedule. All vehicles were soaked overnight between 72±2°F after preconditioning and prior to testing.

All tests were conducted in CE-CERT's Vehicle Emission Research Laboratory (VERL) equipped with a Burke E. Porter 48-inch single-roll electric dynamometer and a Pierburg constant volume sampler (CVS)/dilution tunnel system. Sampling was conducted with VERL's 10-inch-diameter dilution tunnel. CVS flow rates of 350 and 493 standard cubic feet per minute (scfm), respectively, were used for FTP and US06 testing for gasoline vehicles. CVS flow rates of 693 and 856 scfm were used for FTP and US06 testing for M85 and CNG-fueled vehicles. Higher flow rates were used for the US06 cycle to provide greater exhaust dilution due to larger exhaust volumes expected for the more aggressive driving schedule. Some tunnel temperatures in excess of 52°C were still recorded, however, during the most aggressive portions of the US06 cycle. Higher flow rates were used for CNG and M85 vehicles because combustion of these fuels produce higher concentrations of water in the exhaust.

2.4 Particulate Sample Collection

The particulate sampling protocol for this project was designed to provide mass emissions rates, size distributions, and samples for analysis for organic and elemental carbon fractions, metals and inorganic ions, and speciation of the organic fraction of the particulate. The particulate sampling and analysis plan for this project follows:

- For each of the 20 vehicle/fuel combinations, FTP particulate mass emission rates were determined, as well as the fraction of mass below 1.0, 2.5, and 10.0 µm in aerodynamic diameter.
- For each of the 20 vehicle/fuel combinations, particulate samples were collected for analysis of organic and inorganic carbon, and determination of trace elements and ions. FTP samples were analyzed for all five vehicles within each fuel/vehicle group (i.e., CNG Dodge Caravan, RFG Dodge Caravan, M85 Ford Taurus, and RFG Ford Taurus); US06 samples were analyzed for two vehicles within each fuel/vehicle group.

- For each of the four vehicle/fuel groups, samples were collected for detailed speciation of the PAHs, hopanes, and steranes. The samples for each fuel/vehicle group were “pooled” by combining individual samples from within each group. Samples for the FTP for each fuel/vehicle group were “pooled” using samples from all five vehicles. Samples for the US06 for each fuel/vehicle group were “pooled” using samples from only two vehicles.

The dilution tunnel used for sampling was fitted with three sampling probes located about 100 inches downstream of the exhaust mixing flange. The sampling configuration, filter media, and analyses are summarized below.

- Probe 1 was fitted with 47 mm, 2.0 μm Gelman Teflon membrane filters using a Pierburg particle sampling system to obtain total mass particulate emission rates for each phase of the FTP. This probe holds three filter assemblies with automatic sampling for each phase of the FTP. Each filter assembly was fitted with a primary and a backup filter.
- Probe 2 was fitted with a two-way flow splitter. One filter holder was fitted with prefired Pallflex 2500 QAT-UP quartz fiber filters for organic and elemental carbon analyses, and detailed speciation of the particulate PAHs, hopanes, and steranes. Thin stainless-steel rings were placed in front of the quartz fiber filters to provide a more uniform and well-defined deposit for carbon analysis. The quartz filters were backed up using a vapor-phase trap for PAHs consisting of XAD-4 resin (polystyrene divinylbenzene polymer) sandwiched between two polyurethane foam (PUF) plugs for collection of semi-volatile PAHs. The other filter holder was fitted with 47 mm Gelman Teflon membrane filters for analyses of trace elements, and determination of sulfate, nitrate, ammonium, and chloride ions.
- Probe 3 was fitted with a MOUDI cascade impactor for collection of size segregated samples. Uncoated aluminum foils were used for impaction substrates together with 47 mm, 2.0 μm pore size Gelman Teflon membrane after-filters. For each test, the MOUDI was configured using the stages corresponding to cut-points of >18, 10, 3.2, 1.8, and 1.0 μm aerodynamic diameter and fitted with an after-filter to determine the total mass below 10.0, 2.5, and 1.0 μm aerodynamic diameter. Although there is no specific impaction substrate for the collection of 2.5 μm particulate, the mass of particulate below 2.5 μm can be obtained by assuming that half of the mass collected on the 1.8 μm impaction substrate is from sub-2.5 μm particles.

For each test, mass emission rates were determined for each bag of the FTP, using two iterations of the FTP. Samples for chemical analysis on quartz-fiber filters and the PUF/XAD substrate, and Teflon membrane filters were collected cumulatively over both back-to-back FTPs. MOUDI samples were also collected cumulatively over both back-to-back FTPs. Each FTP sequence was performed twice to obtain sufficient sample for mass analysis by bag and chemical analysis. All samples were collected cumulatively over the two to four US06 cycles. Four iterations of the US06 cycle were performed on two vehicles within each fuel/vehicle group to obtain samples for analysis of elemental and organic carbon, trace elements, and ions and “pooled” samples for PAH, hopane, and sterane analyses. Only two iterations were performed on the remaining three vehicles in each fuel/vehicle group to obtain samples for mass analysis.

For the CNG Dodge Caravans and the Ford Tauruses operated on M85, sampling rates for total particulate mass by bag of the FTP (Probe 1) were collected at 80 lpm. Polytetrafluoroethylene (PTFE) and quartz fiber filters for chemical analyses were sampled at 60 lpm. For the conventional RFG vehicles, sampling rates for total particulate mass by bag of the FTP (Probe 1) were collected at 47 lpm. PTFE and quartz fiber filters for chemical analyses were sampled at 30 and 60 lpm, respectively. MOUDI samples for all tests were collected at 30 lpm. It should be noted that higher sampling rates were used for the AFVs to compensate for the increased dilution for these vehicles. All particulate sampling was performed under isokinetic sampling conditions using removable probe tips of different diameters.

2.5 Particulate Sample Analysis

Teflon membrane and aluminum MOUDI substrates were weighed before and after sampling to determine the collected mass using an ATI Orion ultra-microbalance. The microbalance is located in an environmental weighing chamber maintained at a temperature of $25^{\circ}\pm 0.5^{\circ}\text{C}$ and a relative humidity of $40\pm 5\%$. Before and at the completion of sample collection, substrates were preconditioned for at least 24 hours in the environmental chamber before weighing. Particulate mass emission rates were corrected based on the daily tunnel blank measurements, which averaged 0.07 ± 0.11 mg/mi with a range from 0.00 to 0.49 mg/mi. Tunnel blanks were collected daily over a period of time roughly corresponding to Bag 2 of the FTP. The precision for particulate mass emissions measurements is 0.13 mg/mi at one sigma for the FTP tests. Minimum detection limits are about two to three times the measurement precision.

The Teflon membrane filters collected from Probe 2 were utilized for chemical analysis of metals and other trace elements, and sulfate, nitrate, ammonium, and chloride ions. All analyses were conducted by the Desert Research Institute (DRI). Samples were stored in petri dishes in a refrigerator before shipment to DRI. Shipment to DRI was in a cooler with blue ice packs. Metals and other trace elements were analyzed using X-ray fluorescence (XRF). Filters were then extracted in a 60:40 mixture of isopropyl alcohol and distilled, deionized water for nitrate and sulfate analyses using ion chromatography. A separate extraction with distilled, deionized water was used for analysis of chloride and ammonium ions, because the isopropyl alcohol causes interference in the measurements of these two ions. Chloride ions were measured using ion chromatography; ammonium ions were measured using automated colorimetry.

The quartz fiber filters collected at Probe 2 were used for elemental and organic carbon analyses. Quartz fiber filters were obtained from DRI after prebaking at 900°C for three hours to reduce background carbon levels. The filters were shipped in blue ice to the College of Engineering: Center for Environmental Research and Technology (CE-CERT) and stored in a refrigerator until use. After sampling, filters were stored in a refrigerator in petri dishes lined with aluminum foil prior to return shipment to DRI in a cooler with blue ice packs. Elemental and organic carbon analyses were performed by DRI using the thermal optical reflectance method (Chow et al., 1993). Analyses were performed on a 0.512 cm^2 punch from the filter.

PAH/hopane/sterane analyses were performed on the PUF/XAD vapor-phase trap and quartz fiber filters. PUF/XAD backup cartridges were utilized to collect semi-volatile PAH/hopanenes/steranes. XAD resin and PUF cartridges were obtained precleaned from DRI. The XAD resin was cleaned by washing with distilled water, followed by Soxhlet extraction for 24 hours with methanol. The resin was then

drained and Soxhlet extracted for an additional 24 hours with dichloromethane (CH_2Cl_2). The resin was dried in a vacuum oven at 40°C . PUF cartridges were cleaned by first washing with distilled water followed by Soxhlet extraction for 24 hours in acetone, followed by Soxhlet extraction for 24 hours in 10% diethyl ether in hexane. The extracted PUFs were dried in a vacuum oven connected to a water aspirator and dried at room temperature for approximately 2-4 hours. XAD resin and PUF cartridges were stored in a freezer prior to sampling and after sampling prior to return to DRI. XAD and PUF filters were shipped from DRI to CE-CERT and from CE-CERT back to DRI in a cooler with blue ice.

The PUF/XAD vapor trap was combined with the quartz fiber filter from the corresponding test for extraction. This provides a combined sample of semi-volatile and particulate phase PAH/hopanes/steranes. Filter samples from more than one test were combined to provide an adequate sample for analyses, as discussed in section 2.4. Filters were extracted in CH_2Cl_2 for 8 hours. Prior to extraction, deuterated internal standards were added to each sample. Extracts were analyzed by electron impact (EI) gas chromatography/mass spectrometry (GC/MS) technique.

2.6 Alcohol and Carbonyl Analysis

Methanol and carbonyl measurements were collected on a subset of the tests performed on the RFG and M85 test vehicles. For each RFG and M85 vehicle/fuel combination, alcohol and carbonyl measurements were collected on the first of the back-to-back FTPs. Additional alcohol and carbonyl measurements were collected on one US06 test for two of five RFG Dodge Caravans, and two of the five FFV Ford Tauruses on both RFG and M85. Exhaust methanol was collected using water impingers and analyzed with a gas chromatograph/flame ionization detector. Dilute exhaust gas aldehydes and ketones collected on dinitrophenyl-hydrazine (DNPH)-coated silica gel cartridges. DNPH cartridges were analyzed by high performance liquid chromatography (HPLC). Methanol, aldehydes, and ketones were all sampled through a heated line (110°C).

3.0 Emissions Test Results and Discussion

The testing results for particulate and gas phase emissions are summarized in Sections 3.1 and 3.2, respectively. The complete particulate and gas-phase emissions for individual tests are presented in Appendix B. The complete methanol and carbonyl results are presented in Appendix C.

3.1 Emissions Results

The FTP emissions results for the CNG and RFG Dodge Caravans are presented in Table 2 and Figure 1. The particulate emission results are obtained from cumulative particulate samples; the gaseous emissions are the averages over both tests. These results show that the particulate emissions from the RFG and CNG test vehicles are both relatively low and comparable. The resulting particulate emissions are also comparable to those found for newer gasoline vehicles in the more comprehensive study of in-use gasoline vehicles (Norbeck, Durbin, and Truex, 1998). In this work, the average FTP emission rate for 1991-1997 gasoline vehicles was 2.5 mg/mi with a median of 1.2 mg/mi.

For gaseous emissions, the CNG vehicles produced lower NMHC and CO emissions than the RFG vehicles. NMHC emissions from the CNG vehicles were 83% lower than those from the RFG vehicles. CO emissions were 38% lower for the CNG fleet than for the RFG vehicles. Averages were also presented excluding CNG vehicle #1. Although no particular problems were noted with this vehicle, emissions considerably higher than expected for its ultra low emission vehicle (ULEV) certification indicate that this may not have been a representative test vehicle. Excluding CNG vehicle #1, the average CO emission rate for CNG is reduced further to 0.527 g/mi or an overall reduction of about 76%. NO_x emissions for the CNG vehicles were comparable to those for the RFG vehicles for the fleet average, and slightly lower than RFG when CNG vehicle #1 was excluded.

The results for the US06 tests for CNG and RFG Dodge Caravans are presented in Table 3 and Figure 2. Overall, the emissions of CO, NO_x, and PM are all higher than for the FTP, with relatively significant increases in particulate mass emission rates for some of the CNG (#1 and #4) and RFG (#1, #3, and #4) vehicles. Increases relative to the FTP of 72% and 103% were observed for CO and NO_x, respectively, for CNG vehicles over the US06. US06 particulate emissions increased by more than a factor of 5 over the FTP, to 7.76 mg/mi for the CNG vehicles and 6.63 mg/mi for the RFG vehicles. In comparing the CNG and RFG vehicles, trends similar to those observed for the FTP were found. In particular, emissions for NMHC and CO were lower for the CNG vehicles, while emissions for the particulate were similar between the two vehicle groups. Emissions of NMHC were 93% lower for the CNG vehicles than the RFG vehicles, and CO emissions were approximately 85% lower for the CNG vehicles. Excluding CNG vehicle #1 resulted in even further reductions in CNG vehicles, with average emission rates of 0.008 g/mi for NMHC and 1.294 g/mi for CO. NO_x emissions for the US06 were comparable for CNG and RFG over the fleet average, and lower for CNG with CNG vehicle #1 excluded.

Table 2. FTP Weighted Average Emission Results for CNG and RFG Dodge Caravans

1994 CNG Dodge Caravan Results

	Bag 1					Bag 2					Bag 3					Weighted				
	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM
	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi
CNG #1	1.062	0.098	5.626	1.434	1.30	0.969	0.082	4.271	1.142	1.09	0.758	0.065	5.106	1.380	0.48	0.930	0.081	4.780	1.268	0.96
CNG #2	0.661	0.051	1.405	0.729	3.11	0.259	0.049	0.272	0.316	2.34	0.318	0.029	0.681	0.309	1.47	0.358	0.044	0.618	0.399	2.26
CNG #3	0.413	0.042	1.382	0.189	1.30	0.095	0.085	0.359	0.008	2.09	0.171	0.009	0.789	0.041	1.40	0.182	0.055	0.689	0.054	1.74
CNG #4	0.468	0.024	0.893	0.677	1.04	0.122	0.031	0.012	0.394	1.36	0.204	0.022	0.047	0.418	0.85	0.216	0.027	0.204	0.459	1.16
CNG #5	0.470	0.007	2.183	0.406	1.91	0.083	0.007	0.071	0.140	0.63	0.177	0.004	0.395	0.112	0.55	0.188	0.006	0.596	0.187	0.87
Average	0.615	0.044	2.298	0.687	1.73	0.305	0.050	0.997	0.400	1.50	0.325	0.026	1.403	0.452	0.95	0.375	0.043	1.377	0.473	1.40
Average Excluding CNG #1	0.503	0.031	1.466	0.500	1.84	0.140	0.043	0.178	0.214	1.61	0.217	0.016	0.478	0.220	1.07	0.236	0.033	0.527	0.275	1.51

1994 RFG Dodge Caravan Results

	Bag 1					Bag 2					Bag 3					Weighted				
	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM
	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi
RFG #1	0.875	0.816	5.973	0.865	9.06	0.055	0.032	0.577	0.189	0.44	0.146	0.111	1.864	0.317	0.94	0.250	0.216	2.047	0.364	2.36
RFG #2	1.023	0.970	7.749	0.764	1.35	0.031	0.010	0.275	0.169	0.15	0.098	0.078	1.270	0.282	0.28	0.255	0.227	2.093	0.323	0.44
RFG #3	1.308	1.250	6.941	0.870	4.21	0.037	0.010	0.505	0.153	0.34	0.121	0.121	1.535	0.194	1.09	0.322	0.297	2.117	0.312	1.35
RFG #4	1.060	1.005	5.453	0.948	2.51	0.062	0.038	0.957	0.224	0.53	0.147	0.117	2.216	0.345	1.32	0.292	0.259	2.231	0.407	1.16
RFG #5	1.029	0.969	6.952	0.945	2.49	0.061	0.038	0.964	0.223	0.55	0.133	0.101	2.225	0.379	0.46	0.281	0.248	2.548	0.415	0.92
Average	1.059	1.002	6.613	0.878	3.92	0.049	0.025	0.655	0.191	0.40	0.129	0.105	1.822	0.303	0.82	0.280	0.249	2.207	0.364	1.25

Figure 1. FTP Weighted Average Emission Results for CNG and RFG Dodge Caravans

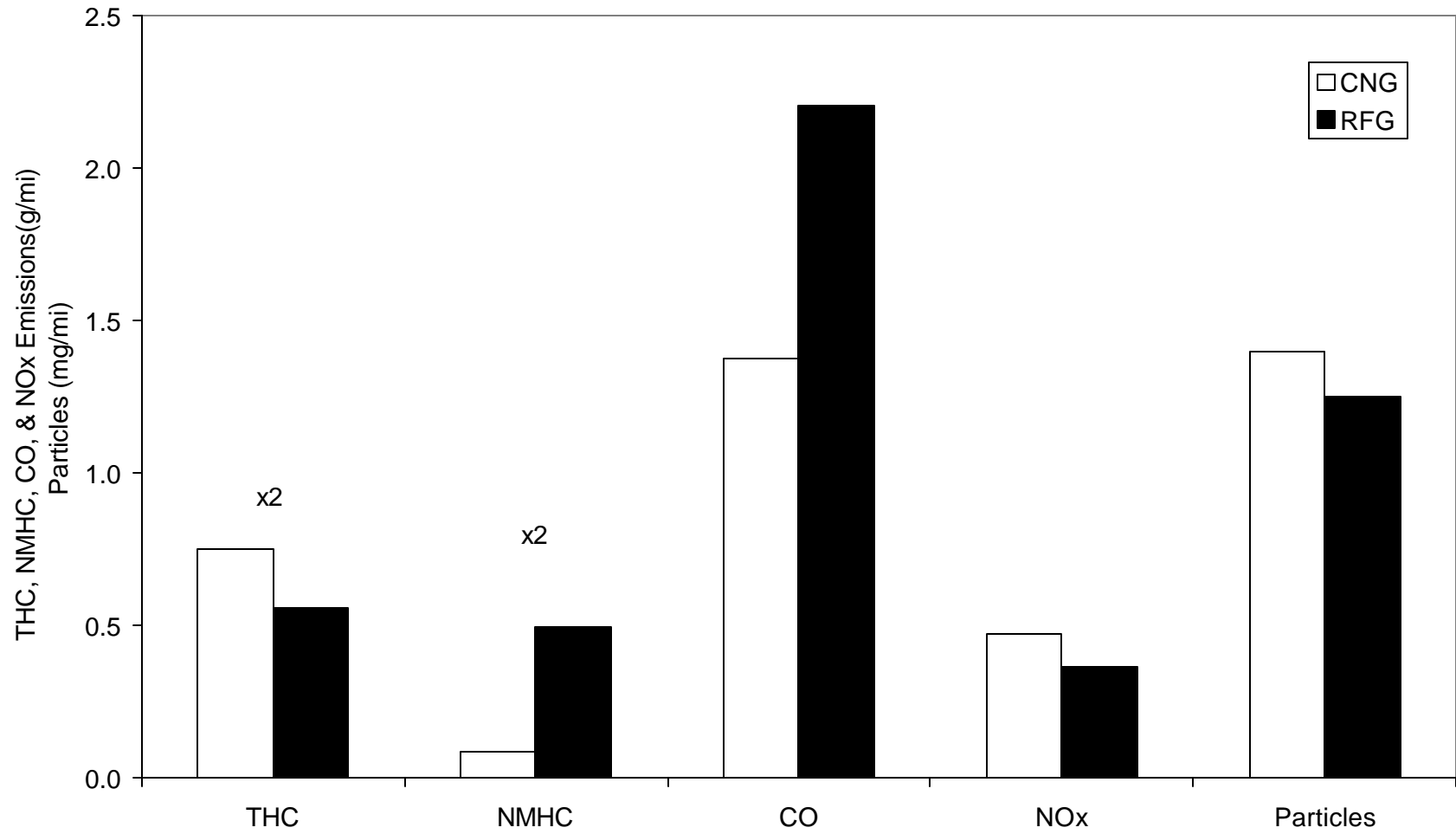


Figure 2. US06 Average Emission Results for CNG and RFG Caravans

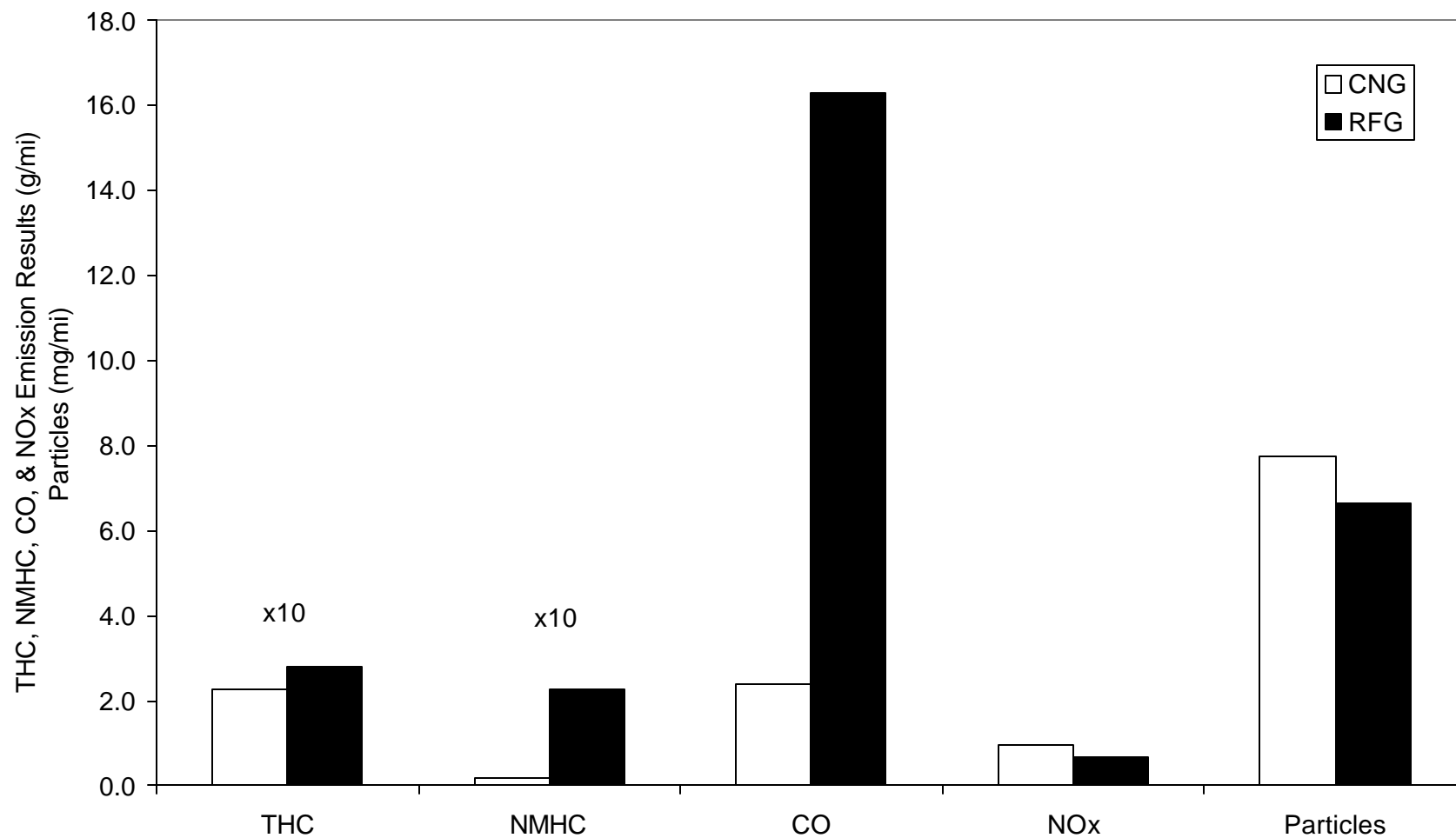


Table 3. US06 Average Emission Results for CNG and RFG Dodge Caravans**1994 CNG Dodge Caravans Results**

	THC g/mi	NMHC g/mi	CO g/mi	NO _x g/mi	PM mg/mi
# 1	0.577	0.055	6.685	3.134	12.46
# 2	0.173	0.012	1.806	0.622	5.24
# 3	0.118	0.003	1.515	0.254	4.74
# 4	0.145	0.007	0.423	0.458	13.77
# 5	0.122	0.008	1.432	0.335	2.60
Average	0.227	0.017	2.372	0.961	7.76
Average Excluding Vehicle#1	0.140	0.008	1.294	0.417	6.59

1994 RFG Dodge Caravans Results

	THC g/mi	NMHC g/mi	CO g/mi	NO _x g/mi	PM mg/mi
# 1	0.236	0.194	9.085	0.712	7.99
# 2	0.160	0.126	10.760	0.487	1.83
# 3	0.294	0.243	17.362	0.563	11.63
# 4	0.410	0.339	25.451	0.761	7.95
# 5	0.290	0.238	18.780	0.878	3.74
Average	0.278	0.228	16.288	0.680	6.63

The FTP emissions results for the FFV Ford Tauruses are presented in Table 4 and Figure 3. Particulate emission rates for the FFV Ford Tauruses were relatively low and near the detection limits for some vehicles, but were comparable for M85 and RFG. These particulate mass emission rates are also comparable to those observed for newer gasoline vehicles in CE-CERT's more comprehensive study of in-use vehicles (Norbeck, Durbin, and Truex, 1998). For gaseous emissions, the Ford Tauruses produced 27% lower NO_x and 36% higher CO emissions on M85 than on RFG. Organic material hydrocarbon equivalent emissions (OMHCE), calculated using oxygenated carbon mass as CH_{1.85}, were 38% higher on M85 than on RFG. Total hydrocarbons excluding methanol were lower for M85 than RFG, however. As expected, both methanol and formaldehyde emissions were considerably higher for M85 than for RFG. For the M85 vehicles, methanol emissions can primarily be attributed to Bag 1 cold-start emissions. FTP methanol and formaldehyde emissions results for the Ford Tauruses are presented in Table 5.

Table 4. FTP Average Emission Results for FFV Ford Tauruses on M85 and RFG

	Bag 1					Bag 2					Bag 3					Weighted				
	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi
M85 #1	0.716	0.335	6.372	0.451	0.77	0.025	0.019	1.619	0.199	0.06	0.057	0.034	2.005	0.317	0.26	0.177	0.088	2.709	0.284	0.26
M85 #2	0.604	0.247	5.645	0.346	1.44	0.033	0.029	0.478	0.165	0.70	0.035	0.030	0.949	0.220	0.30	0.152	0.074	1.675	0.218	0.75
M85 #3	0.777	0.258	5.775	0.372	0.53	0.034	0.023	0.824	0.167	0.56	0.056	0.046	1.940	0.177	0.27	0.194	0.078	2.152	0.212	0.47
M85 #4	0.674	0.266	6.868	0.373	2.69	0.021	0.014	1.001	0.175	0.94	0.052	0.040	1.567	0.253	1.01	0.165	0.073	2.369	0.238	1.32
M85 #5	1.086	0.352	9.286	0.151	1.26	0.025	0.016	1.110	0.058	0.50	0.029	0.024	1.807	0.114	0.69	0.245	0.088	2.995	0.093	0.71
Average	0.772	0.309	6.789	0.338	1.35	0.028	0.021	1.006	0.153	0.57	0.050	0.038	1.653	0.216	0.52	0.187	0.080	2.380	0.209	0.70

	Bag 1					Bag 2					Bag 3					Weighted				
	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	OMHCE g/mi	THC g/mi	CO g/mi	NO _x g/mi	PM mg/mi
RFG #1	0.648	0.640	5.808	0.641	0.55	0.021	0.020	0.838	0.161	0.09	0.089	0.089	1.327	0.502	0.05	0.169	0.167	2.000	0.354	0.17
RFG #2	0.479	0.473	6.370	0.415	1.78	0.010	0.009	0.128	0.132	0.13	0.032	0.032	0.371	0.299	0.03	0.113	0.111	1.491	0.237	0.45
RFG #3	0.513	0.507	5.740	0.533	1.09	0.019	0.018	0.451	0.180	0.33	0.076	0.076	0.953	0.340	0.44	0.137	0.135	1.680	0.297	0.52
RFG #4	0.604	0.595	5.413	0.469	2.53	0.011	0.008	0.736	0.163	2.00	0.080	0.079	0.908	0.355	0.49	0.152	0.149	1.767	0.281	1.69
RFG #5	0.420	0.413	5.981	0.479	0.68	0.016	0.015	0.624	0.136	0.41	0.043	0.043	0.967	0.353	0.32	0.107	0.104	1.826	0.266	0.44
Average	0.533	0.526	5.862	0.507	1.33	0.015	0.014	0.555	0.154	0.59	0.064	0.064	0.905	0.370	0.27	0.136	0.133	1.753	0.287	0.65

Note: THC = Total flame ionization detector (FID) hydrocarbons excluding methanol
OMHCE = calculated using the oxygenated carbon mass as CH_{1.85}

Figure 3. FTP Weighted Average Emission Results for M85 and RFG FFV Ford Tauruses

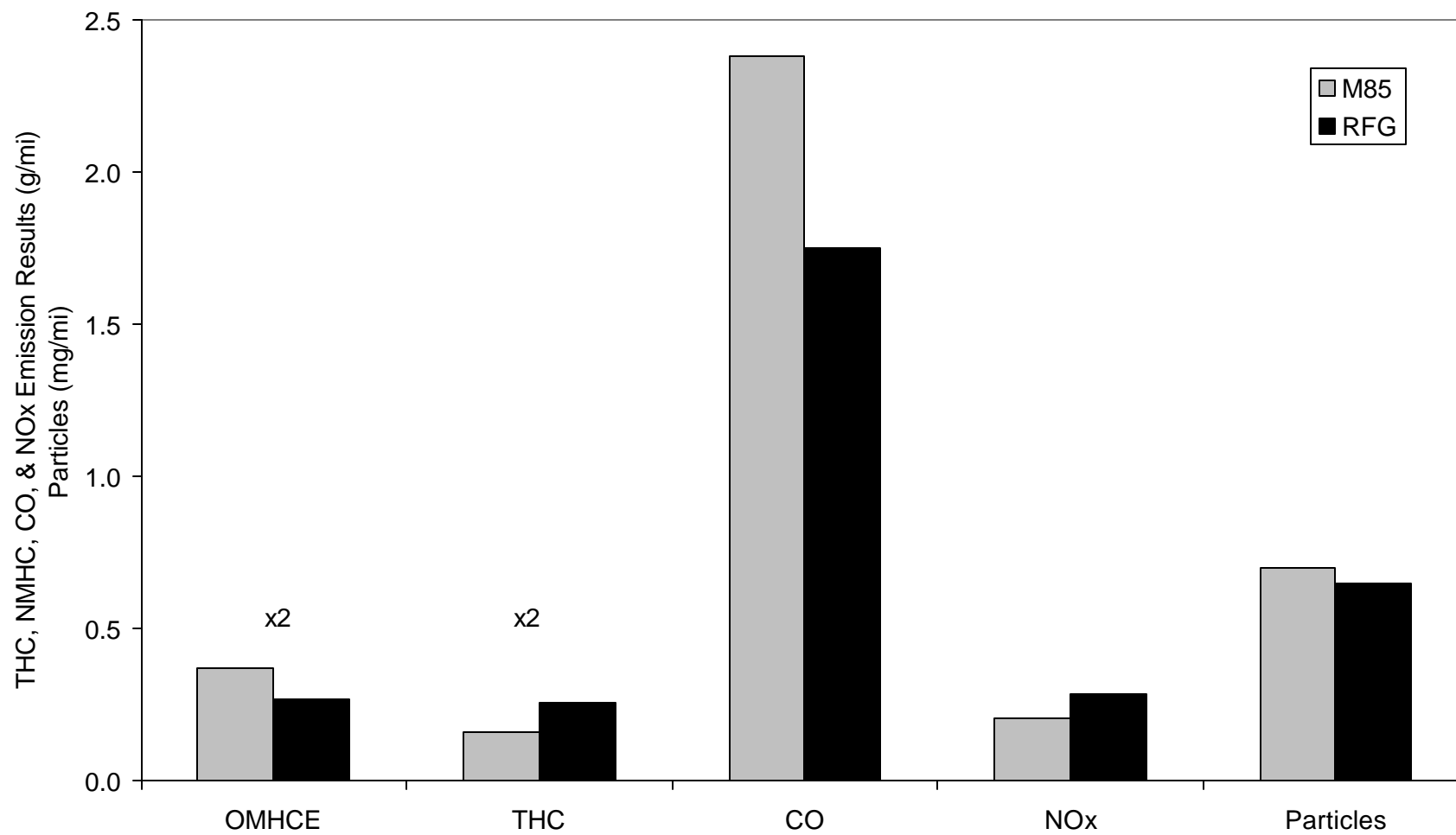


Table 5. FTP Methanol and Formaldehyde Results for Ford Tauruses on M85 and RFG**1994 FFV Ford Taurus (on M85) Results**

	Bag 1		Bag 2		Bag 3		Weighted	
	Methanol mg/mi	Formaldehyde mg/mi	Methanol mg/mi	Formaldehyde mg/mi	Methanol mg/mi	Formaldehyde mg/mi	Methanol mg/mi	Formaldehyde mg/mi
M85 #1	825.7	49.7	1.8	11.0	51.8	2.2	185.6	16.6
M85 #2	777.7	43.6	0.0	9.3	10.7	1.8	164.4	14.4
M85 #3	1140.1	55.2	12.3	12.4	19.9	2.3	248.1	18.5
M85 #4	248.1	54.6	2.4	12.5	26.1	2.0	191.2	18.3
M85 #5	1585.9	103.2	5.1	13.2	10.4	1.5	332.8	28.6
Average	915.5	61.3	4.3	11.7	23.8	2.0	224.4	19.3

1994 FFV Ford Taurus (on RFG) Results

	Bag 1		Bag 2		Bag 3		Weighted	
	Methanol mg/mi	Formaldehyde mg/mi	Methanol mg/mi	Formaldehyde mg/mi	Methanol mg/mi	Formaldehyde mg/mi	Methanol mg/mi	Formaldehyde mg/mi
RFG #1	7.4	9.1	0.0	2.7	0.0	1.3	1.5	3.6
RFG #2	7.1	7.6	0.0	2.0	0.0	0.9	1.5	2.9
RFG #3	5.4	7.8	0.0	2.8	0.0	0.8	1.1	3.3
RFG #4	7.4	13.3	0.0	7.0	0.0	1.0	1.5	6.6
RFG #5	10.9	6.0	0.0	1.8	0.0	0.5	2.3	2.3
Average	7.6	8.8	0.0	3.3	0.0	0.9	1.6	3.7

US06 emissions results are presented in Table 6 and Figure 4 for the FFV Ford Tauruses on M85 and RFG, respectively. Total and non-methane hydrocarbons are presented in these tables without correction for the FID response to methanol because these emissions were collected only on a limited number of US06 tests and not for all vehicles. CO, NO_x, and PM were all higher for the US06 cycle than for the FTP. Increases relative to the FTP of 212% and 143% were observed for CO and NO_x, respectively, for M85 vehicles over the US06. US06 particulate emissions increased by a factor of 5-6 over the FTP, to 3.62 mg/mi for the M85 vehicles and 4.11 mg/mi for the RFG vehicles. Particulate emissions were comparable for M85 and RFG over the US06, while THC, NMHC, CO, and NO_x emissions were all lower for M85 compared with RFG. The reductions for M85 relative to RFG were 68%, 72%, 33%, and 44%, respectively, for THC, NMHC, CO, and NO_x. Methanol and formaldehyde emissions were very low for the US06 for both the M85 and RFG.

Table 6. US06 Average Emission Results for FFV Ford Tauruses on M85 and RFG**1994 FFV Ford Tauruses (on M85) Results**

	THC*	NMHC*	CO	NO _x	PM	Methanol	Formaldehyde
	g/mi	g/mi	g/mi		mg/mi	mg/mi	mg/mi
# 1	0.019	0.016	2.395	0.947	2.91	0.0	6.0
# 2	0.031	0.024	2.136	0.567	3.50	3.0	3.4
# 3	0.072	0.057	7.751	0.356	2.96	-	-
# 4	0.050	0.038	5.615	0.466	1.63	-	-
# 5	0.083	0.057	19.234	0.201	7.08	-	-
Average	0.051	0.038	7.426	0.507	3.62	1.5	4.7

1994 FFV Ford Tauruses (on RFG) Results

	THC*	NMHC*	CO	NO _x	PM	Methanol	Formaldehyde
	g/mi	g/mi	g/mi		mg/mi	mg/mi	mg/mi
# 1	0.259	0.233	7.381	1.374	2.62	4.0	2.1
# 2	0.069	0.060	2.679	0.988	2.47	0.0	2.1
# 3	0.159	0.130	10.659	0.671	3.04	-	-
# 4	0.138	0.116	8.935	0.788	4.12	-	-
# 5	0.182	0.136	25.449	0.672	8.32	-	-
Average	0.161	0.135	11.020	0.898	4.11	2.0	2.1

* uncorrected for response of FID to methanol

3.2 Particle Size Distributions

Average particulate size distributions for total mass below 10, 2.5, and 1.0 μm aerodynamic diameter are presented in Figures 5 and 6, respectively, for the FTP and US06, along with the standard deviation between tests. Results for individual tests are presented in Appendix D. The results show that the majority of the particulate mass was below 10 μm in aerodynamic diameter (77%-92%) with 58%-82% of the mass below 2.5 μm , and 42%-77% below 1.0 μm . The fractions of mass in the smaller size regions, however, are generally less than those observed in other studies of smoking, diesel and gasoline vehicles (Durbin et al., 1999; Norbeck, Durbin, and Truex 1998; Whitney, 1998). In this regard, it is important to note that it is difficult to measure accurate size distributions from such low-emitting vehicles, because the mass collected on individual impaction substrates is often near or at the minimum detection limits ($\sim 4 \mu\text{g}$). This problem has been noted in other studies (Whitney, 1997), and is indicated by the large errors associated with some test results, as presented in Appendix D. This is particularly relevant for the FTP testing with relatively low-mass emissions. It is also possible that the contribution of the re-entrained particulate, which has been attributed to a coarse mode between 1 and 10 μm in aerodynamic diameter (Marple et al., 1986), is greater for low-emitting vehicles or when vehicles are driven over more aggressive cycles. Appendix E presents a comparison of mass emission rates for the Teflon filters with those for the MOUDI. Differences in particulate mass emissions rates for the MOUDI and PTFE filters were generally less than 25%. Particulate emission rates did differ by a factor of two or more, however, for some tests, with the greatest discrepancies observed for FTP tests with relatively low-mass emissions.

Figure 4. US06 Average Emission Results for M85 and RFG FFV Ford Tauruses

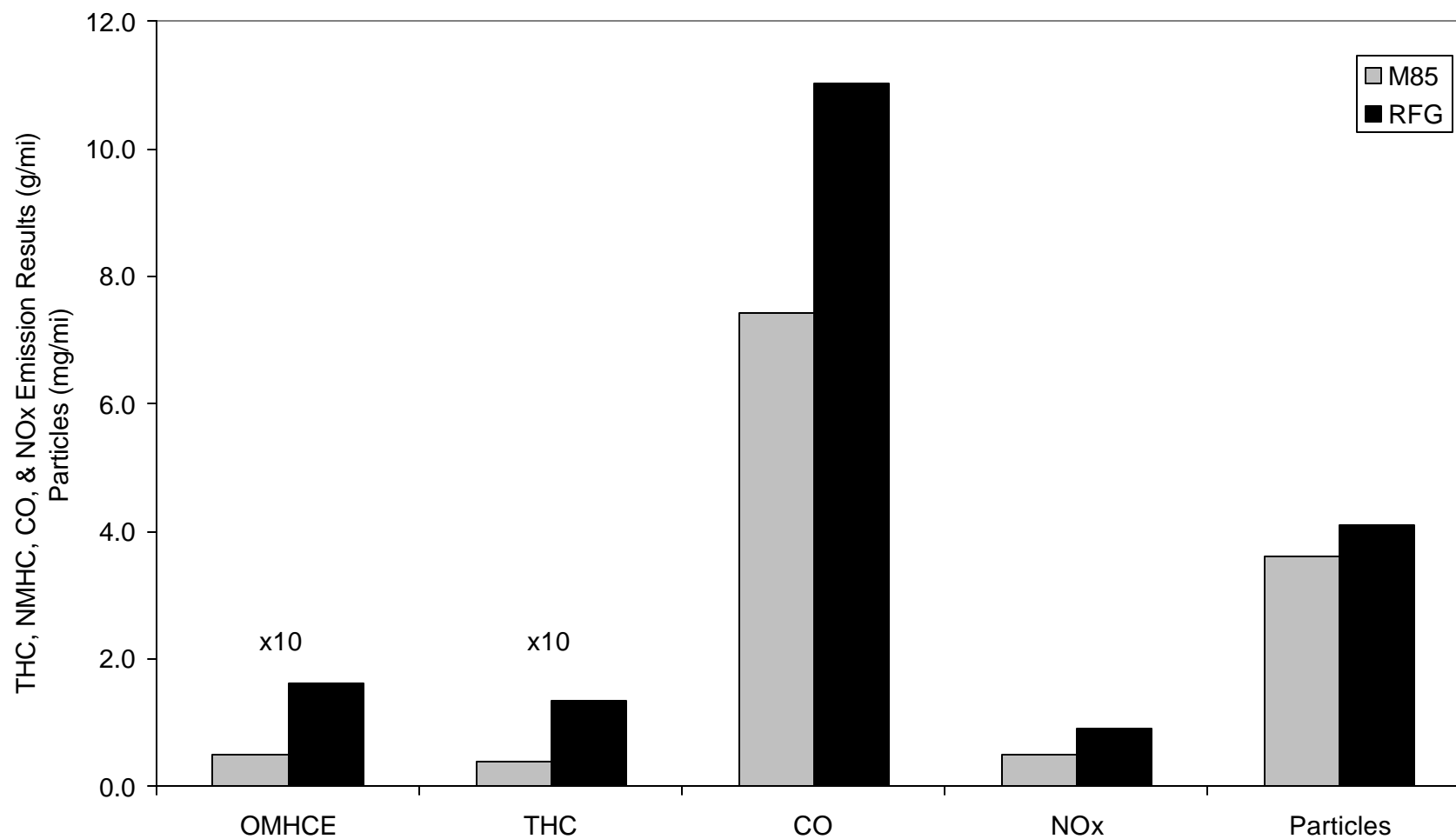


Figure 5. Average Particle Size Distributions for FTP

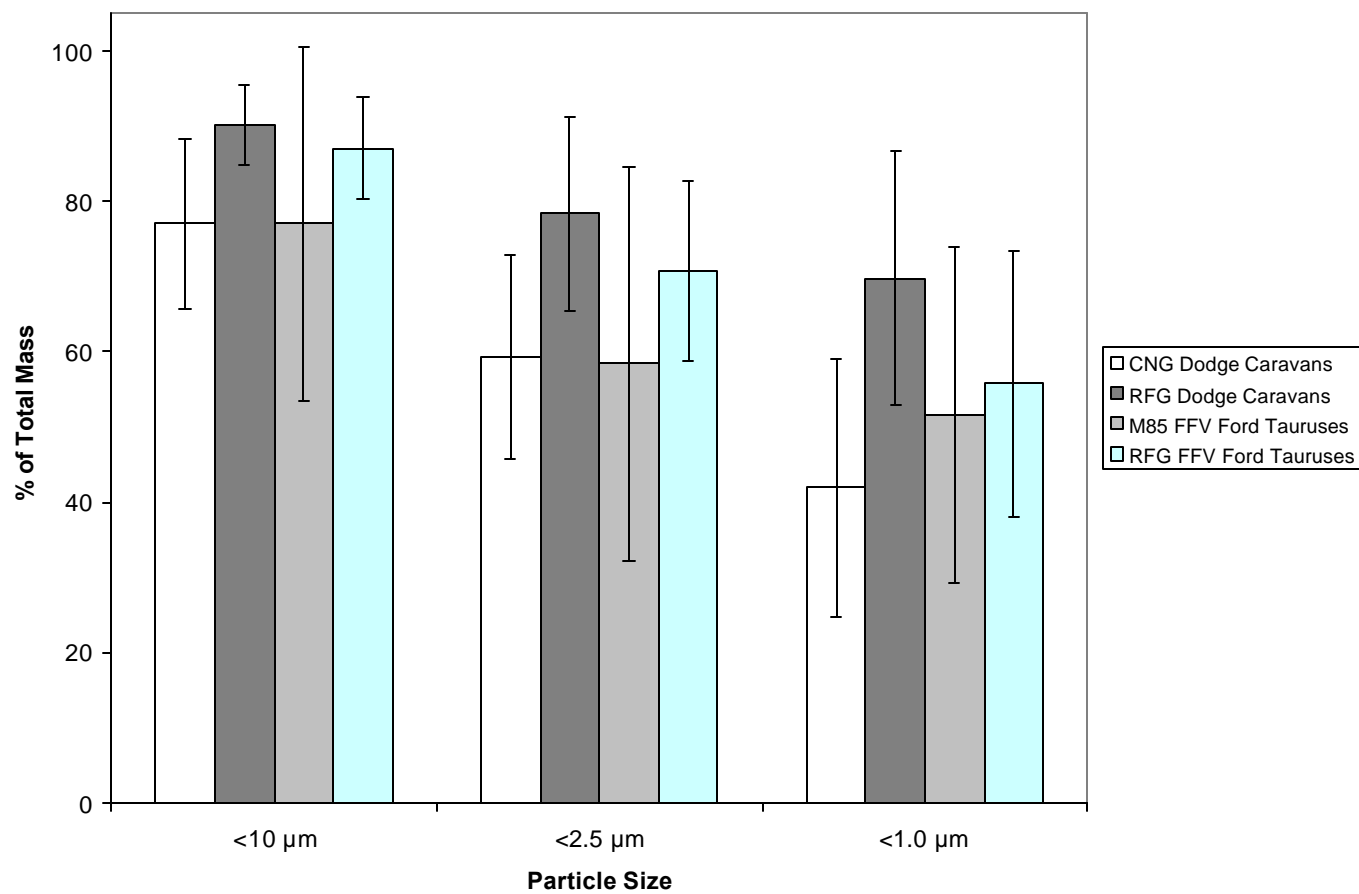
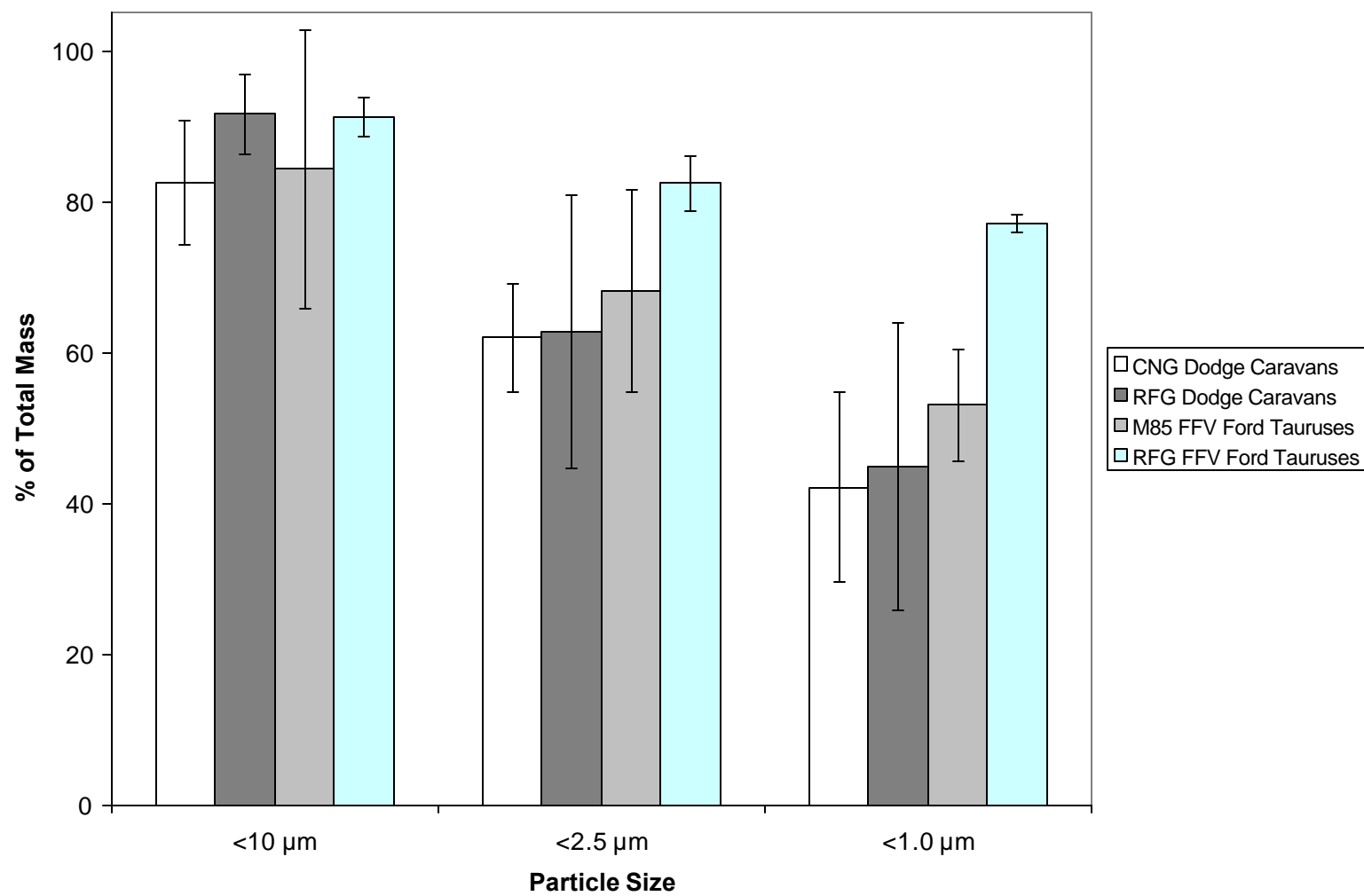


Figure 6. Average Particle Size Distributions for US06



4.0 Chemical Analysis Results and Discussion

4.1 Chemical Species

Chemical analyses were conducted for samples from each fuel/vehicle group. The average FTP emission results for individual chemical species are presented in Table 7 and Figure 7 for the CNG/RFG Dodge Caravans and in Table 8 and Figure 8 for the M85/RFG Ford Tauruses. The average US06 emission results for individual chemical species are presented in Table 9 and Figure 9 for the CNG and RFG Dodge Caravans and in Table 10 and Figure 10 for the M85 and RFG Ford Tauruses. Tables 7-10 include average emission rates, standard deviations of the rates, maximum and minimum values, and average uncertainties for the FTP. The emission rates are corrected for the contribution of trace species detected in the dilution tunnel, and as a result, include some negative values. The error for each measurement is calculated by propagating the uncertainty for the chemical analysis and sampling volumes. Chemical components whose concentrations are at least twice the average uncertainty are shown in bold. Only chemical species with concentrations that were at least twice the average uncertainty for at least one fuel/vehicle group are presented in Figures 7-10. Full chemical analysis results for individual vehicle tests are presented in Appendices F and G, respectively, for the FTP and US06.

For the FTP, emission rates for the individual chemical species are all relatively low. Elemental and organic carbon are prominent species observed for the CNG, RFG, and M85 vehicles. It should be noted, however, that average organic carbon emissions are only greater than twice the average uncertainty for the CNG Dodge Caravans because of the high blank levels of organic carbon. Other species with average concentrations that were at least twice the average uncertainty include NO_3^- , SO_4^{2-} , Mg, Al, Si, P, S, Cl, Ca, Fe, Cu, and Zn. These species include possible fuel derived (SO_4^{2-} , S) and oil- (Mg, P, Ca, Zn) and wear- (Fe, Al) derived components, most of which have been observed in previous studies (Cadde et al., 1997; Sagebiel et al., 1997; Hildemann, Markowski, and Cass, 1991, and Watson et al., 1994). These elements are all observed in trace quantities, however, with emissions levels exceeding 0.05 mg/mi for only the RFG Dodge Caravans.

The chemical species emission levels are higher for the US06, as expected based on the mass emission rates. Elemental and organic carbon were again prominent constituents of the particulate for the US06 cycles. Other species identified at least twice the average uncertainty for at least one of the vehicle fuel groups include NO_3^- , SO_4^{2-} , Cl, NH_4^+ , Mg, Al, Si, P, S, Cl, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Br, Zr, and Pb. This includes many of the same elements identified for the FTP tests. Si emissions rates were relatively high for the US06 cycle. The Si mass emission rates are similar to those observed in the Orange County Remote Sensing study (Cadde et al., 1997), where the average pre-repair emission rate of elemental Si was 1.27 mg/mi (0.65 mg/mi with outliers removed). Fe emissions rates were also prominent for the CNG and RFG Dodge Caravans indicating a wear-derived contribution to the particulate.

Figure 7. PM Chemical Mass Emission Rates for CNG/RFG Dodge Caravans for FTP

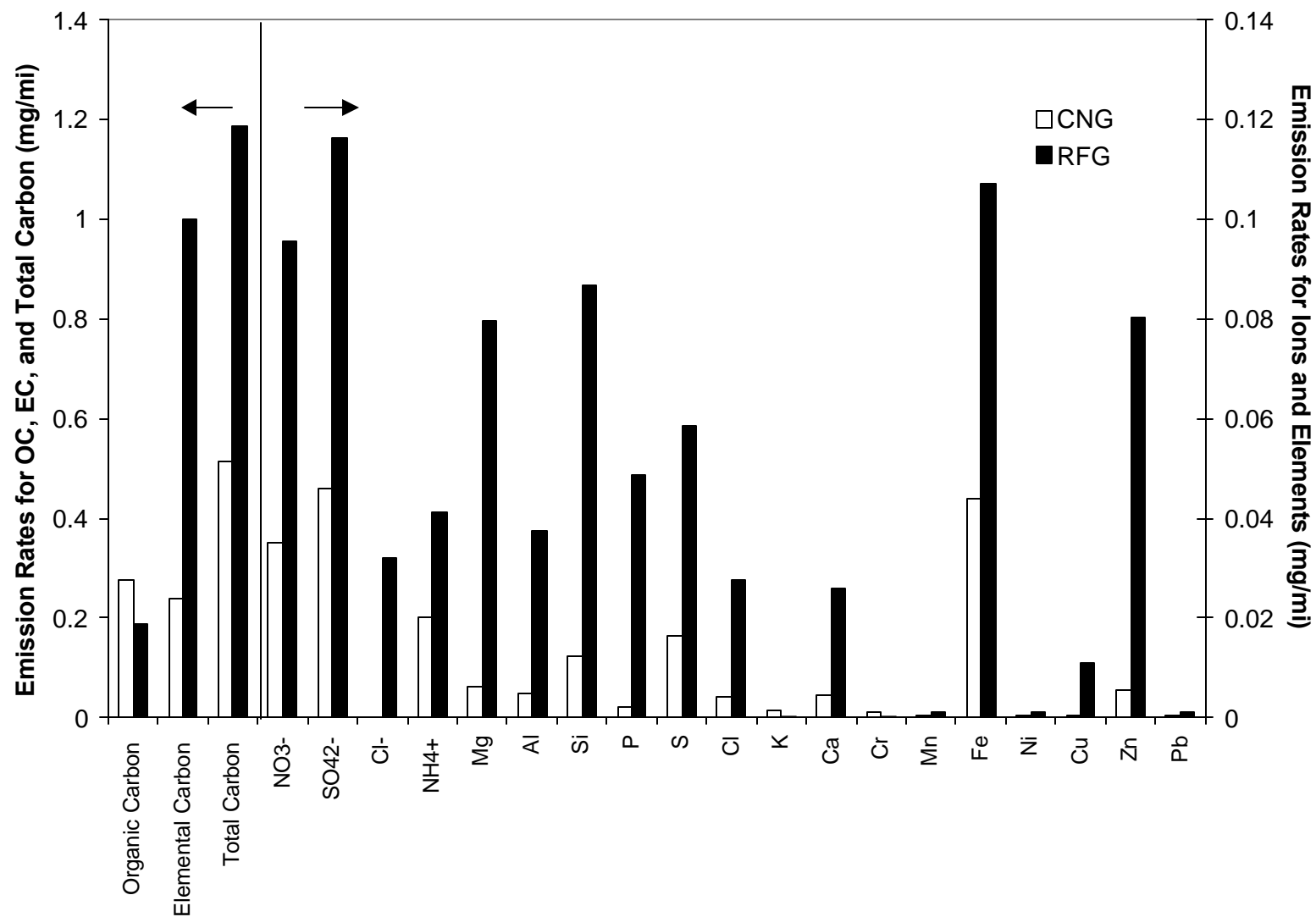


Figure 8. PM Chemical Mass Emission Rates for M85/RFG Ford Tauruses for FTP

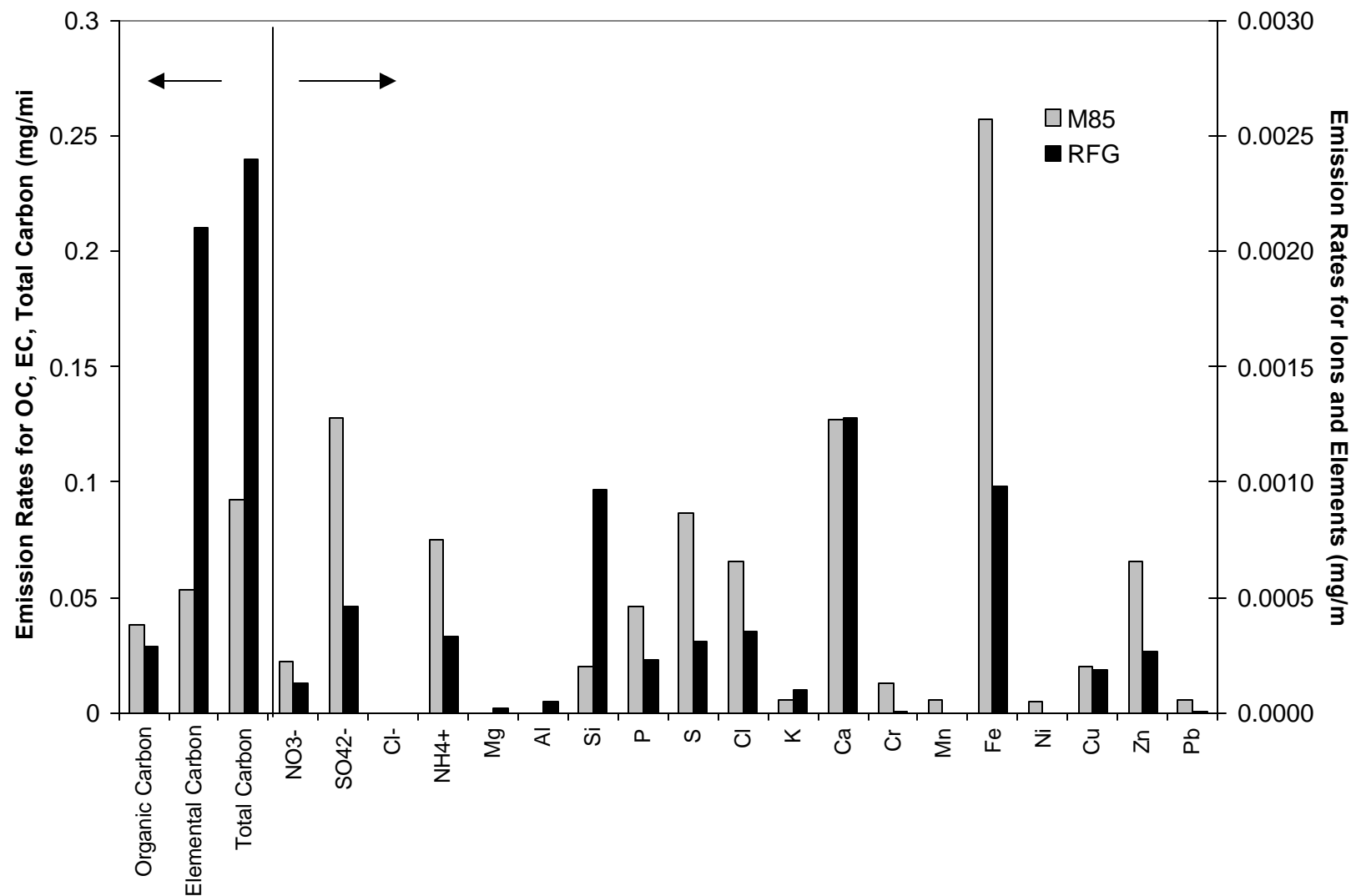


Figure 9. PM Chemical Mass Emission Rates for CNG/RFG Dodge Caravans for US06

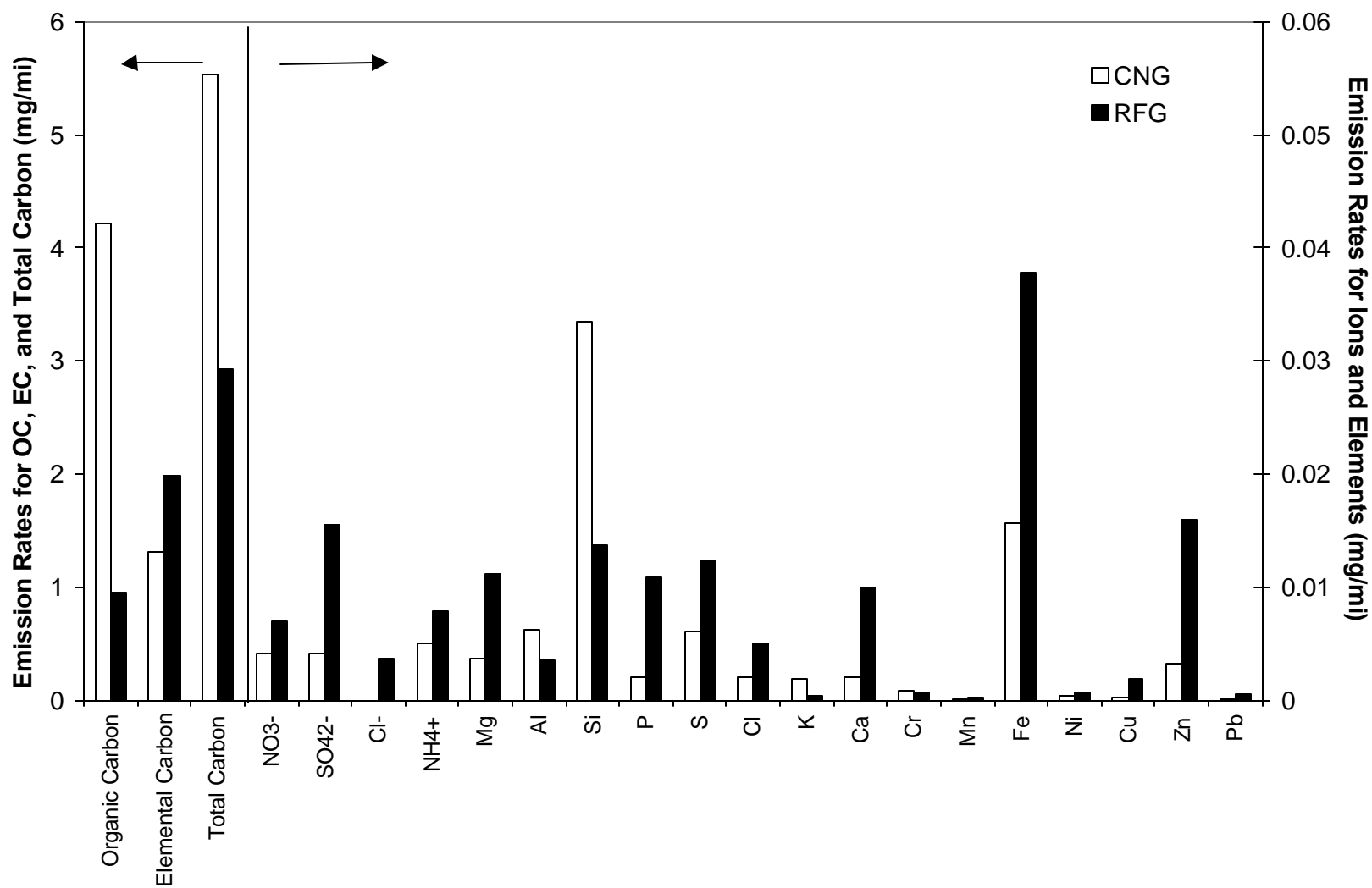
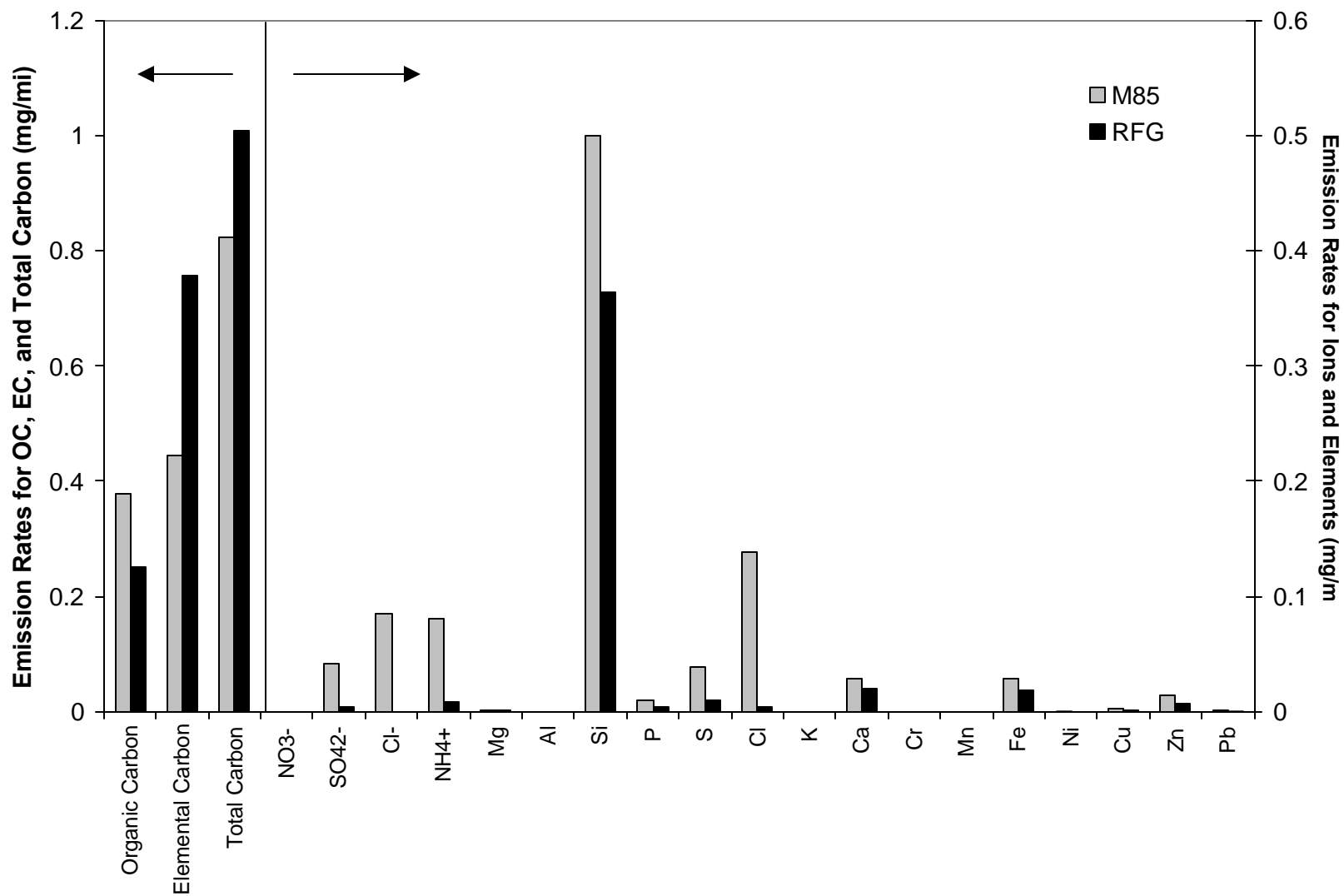


Figure 10. PM Chemical Mass Emission Rates for M85/RFG Ford Tauruses



**Table 7. Statistics for CNG and RFG Dodge Caravans for FTP PM
Chemical Species Emission Rates (mg/mi)**

Species	CNG Dodge Caravans					RFG Dodge Caravans				
	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.
Organic Carbon	0.2777	0.2585	0.1095	0.6870	0.0034	0.1875	0.3523	0.1033	0.7405	-0.1465
Elemental Carbon	0.2376	0.2591	0.0381	0.6768	-0.0001	0.9998	0.9358	0.1021	2.5819	0.2865
Total Carbon	0.5153	0.4053	0.1299	0.9230	0.0033	1.1876	1.2840	0.1728	3.3239	0.1400
NO ₃ ⁻	0.0351	0.0363	0.0156	0.0942	-0.0044	0.0955	0.2049	0.0343	0.4612	-0.0135
SO ₄ ²⁻	0.0459	0.0576	0.0153	0.1483	0.0144	0.1162	0.2363	0.0336	0.5380	-0.0104
Cl ⁻	-0.0015	0.0040	0.0134	0.0033	-0.0059	0.0321	0.0880	0.0314	0.1896	-0.0100
NH ₄ ⁺	0.0203	0.0167	0.0136	0.0493	0.0079	0.0411	0.0717	0.0311	0.1687	0.0037
Na	-0.0019	0.0043	0.0250	0.0030	-0.0063	-0.0047	0.0035	0.0831	0.0016	-0.0063
Mg	0.0063	0.0087	0.0083	0.0217	0.0003	0.0798	0.1724	0.0174	0.3882	0.0006
Al	0.0049	0.0058	0.0038	0.0113	-0.0005	0.0376	0.0791	0.0079	0.1791	0.0002
Si	0.0124	0.0114	0.0018	0.0294	0.0020	0.0868	0.1859	0.0094	0.4193	0.0004
P	0.0020	0.0025	0.0012	0.0060	-0.0007	0.0488	0.0987	0.0057	0.2253	0.0003
S	0.0165	0.0144	0.0018	0.0414	0.0067	0.0584	0.1160	0.0060	0.2658	0.0011
Cl	0.0043	0.0037	0.0028	0.0105	0.0017	0.0276	0.0559	0.0056	0.1276	0.0001
K	0.0016	0.0022	0.0023	0.0042	-0.0014	0.0001	0.0019	0.0087	0.0034	-0.0009
Ca	0.0046	0.0049	0.0018	0.0131	0.0012	0.0260	0.0388	0.0042	0.0947	0.0008
Ti	0.0008	0.0007	0.0129	0.0019	0.0000	0.0024	0.0044	0.0308	0.0103	0.0000
V	0.0003	0.0003	0.0061	0.0009	0.0000	0.0016	0.0032	0.0129	0.0073	0.0000
Cr	0.0010	0.0012	0.0017	0.0029	0.0000	0.0002	0.0003	0.0035	0.0006	0.0000
Mn	0.0005	0.0004	0.0010	0.0009	0.0000	0.0010	0.0019	0.0025	0.0043	-0.0001
Fe	0.0440	0.0112	0.0040	0.0569	0.0274	0.1070	0.1798	0.0097	0.4284	0.0190
Co	0.0001	0.0001	0.0010	0.0002	0.0000	0.0000	0.0000	0.0025	0.0000	0.0000
Ni	0.0003	0.0006	0.0006	0.0013	-0.0001	0.0011	0.0024	0.0017	0.0053	-0.0001
Cu	0.0003	0.0003	0.0006	0.0007	0.0000	0.0109	0.0231	0.0016	0.0523	0.0000
Zn	0.0054	0.0037	0.0007	0.0111	0.0018	0.0804	0.1652	0.0074	0.3759	0.0010
Ga	-0.0001	0.0001	0.0010	0.0001	-0.0002	-0.0001	0.0000	0.0025	-0.0001	-0.0002
As	0.0000	0.0000	0.0012	0.0000	0.0000	0.0003	0.0006	0.0030	0.0014	0.0000
Se	0.0000	0.0000	0.0006	0.0001	0.0000	0.0000	0.0001	0.0015	0.0001	0.0000
Br	0.0000	0.0001	0.0006	0.0001	-0.0001	0.0002	0.0006	0.0014	0.0013	-0.0001
Rb	-0.0001	0.0000	0.0005	0.0000	-0.0001	0.0002	0.0005	0.0013	0.0011	-0.0001
Sr	0.0001	0.0001	0.0006	0.0002	0.0000	0.0000	0.0001	0.0014	0.0001	0.0000
Y	-0.0001	0.0001	0.0007	0.0000	-0.0001	0.0005	0.0011	0.0018	0.0024	-0.0001
Zr	0.0001	0.0001	0.0008	0.0003	0.0000	0.0005	0.0011	0.0020	0.0024	0.0000
Mo	0.0001	0.0001	0.0015	0.0002	0.0000	0.0007	0.0017	0.0038	0.0037	0.0000
Pd	0.0007	0.0009	0.0043	0.0018	0.0000	0.0005	0.0006	0.0103	0.0013	0.0000
Ag	-0.0007	0.0007	0.0050	0.0002	-0.0012	0.0063	0.0145	0.0124	0.0323	-0.0010
Cd	-0.0002	0.0004	0.0051	0.0002	-0.0007	0.0005	0.0013	0.0126	0.0025	-0.0007
In	-0.0002	0.0007	0.0062	0.0010	-0.0007	0.0048	0.0113	0.0153	0.0250	-0.0007
Sn	0.0003	0.0006	0.0080	0.0014	0.0000	0.0051	0.0107	0.0198	0.0242	0.0000
Sb	0.0006	0.0006	0.0093	0.0014	0.0000	0.0092	0.0198	0.0227	0.0445	0.0000
Ba	-0.0113	0.0029	0.0343	-0.0065	-0.0132	-0.0023	0.0224	0.0846	0.0378	-0.0132
La	-0.0094	0.0086	0.0456	0.0060	-0.0133	-0.0004	0.0219	0.1118	0.0377	-0.0133
Au	-0.0001	0.0002	0.0017	0.0002	-0.0002	-0.0002	0.0001	0.0054	-0.0001	-0.0002
Hg	-0.0002	0.0000	0.0014	-0.0002	-0.0002	-0.0002	0.0000	0.0034	-0.0002	-0.0002
Ti	-0.0002	0.0000	0.0013	-0.0002	-0.0002	-0.0002	0.0000	0.0032	-0.0002	-0.0002
Pb	0.0005	0.0003	0.0017	0.0007	0.0000	0.0010	0.0021	0.0043	0.0047	0.0000
U	0.0000	0.0001	0.0013	0.0001	0.0000	0.0007	0.0016	0.0031	0.0035	0.0000

**Table 8. Statistics for M85 and RFG Ford Tauruses for FTP PM
Chemical Species Emission Rates (mg/mi)**

Species	M85 Ford Tauruses					RFG Ford Tauruses				
	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.
Organic Carbon	0.0380	0.1106	0.1049	0.1813	-0.1139	0.0292	0.2694	0.1037	0.4974	-0.1405
Elemental Carbon	0.0537	0.0540	0.0247	0.1255	-0.0048	0.2104	0.1000	0.0285	0.3697	0.1283
Total Carbon	0.0921	0.1628	0.1134	0.3068	-0.1170	0.2395	0.3217	0.1135	0.7383	-0.0079
NO ₃ ⁻	0.0022	0.0109	0.0144	0.0175	-0.0088	0.0013	0.0128	0.0141	0.0197	-0.0136
SO ₄ ²⁻	0.0128	0.0220	0.0139	0.0374	-0.0217	0.0046	0.0302	0.0136	0.0421	-0.0267
Cl ⁻	-0.0035	0.0038	0.0134	0.0025	-0.0073	-0.0071	0.0023	0.0130	-0.0045	-0.0096
NH ₄ ⁺	0.0075	0.0125	0.0137	0.0218	-0.0116	0.0033	0.0141	0.0133	0.0238	-0.0116
Na	0.0102	0.0026	0.0222	0.0139	0.0065	-0.0015	0.0042	0.0233	0.0039	-0.0063
Mg	-0.0017	0.0027	0.0095	0.0025	-0.0049	0.0002	0.0043	0.0088	0.0064	-0.0054
Al	-0.0021	0.0011	0.0047	-0.0007	-0.0037	0.0005	0.0010	0.0038	0.0019	-0.0007
Si	0.0020	0.0029	0.0015	0.0050	-0.0015	0.0097	0.0090	0.0014	0.0204	0.0020
P	0.0046	0.0031	0.0012	0.0074	-0.0005	0.0023	0.0016	0.0011	0.0045	0.0006
S	0.0087	0.0082	0.0013	0.0174	-0.0050	0.0031	0.0040	0.0010	0.0095	-0.0009
Cl	0.0066	0.0056	0.0028	0.0136	0.0008	0.0035	0.0030	0.0028	0.0087	0.0012
K	0.0006	0.0010	0.0022	0.0019	-0.0006	0.0010	0.0014	0.0022	0.0034	-0.0003
Ca	0.0127	0.0068	0.0021	0.0187	0.0024	0.0128	0.0061	0.0020	0.0229	0.0081
Ti	0.0009	0.0009	0.0129	0.0019	0.0001	0.0010	0.0010	0.0127	0.0021	0.0000
V	0.0001	0.0001	0.0062	0.0003	0.0000	0.0001	0.0002	0.0062	0.0004	0.0000
Cr	0.0013	0.0024	0.0018	0.0056	0.0000	0.0001	0.0002	0.0018	0.0005	0.0000
Mn	0.0006	0.0015	0.0011	0.0034	-0.0001	-0.0001	0.0000	0.0010	0.0000	-0.0001
Fe	0.0257	0.0084	0.0023	0.0346	0.0149	0.0098	0.0055	0.0011	0.0166	0.0042
Co	0.0002	0.0001	0.0008	0.0004	0.0000	0.0000	0.0001	0.0007	0.0001	0.0000
Ni	0.0005	0.0008	0.0006	0.0018	0.0000	0.0000	0.0001	0.0006	0.0001	-0.0001
Cu	0.0020	0.0012	0.0006	0.0035	0.0004	0.0019	0.0016	0.0006	0.0044	0.0000
Zn	0.0066	0.0030	0.0008	0.0098	0.0025	0.0027	0.0010	0.0006	0.0041	0.0016
Ga	-0.0001	0.0001	0.0010	0.0000	-0.0002	-0.0002	0.0000	0.0010	-0.0002	-0.0002
As	0.0000	0.0001	0.0012	0.0001	0.0000	0.0000	0.0000	0.0012	0.0001	0.0000
Se	0.0001	0.0000	0.0006	0.0001	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000
Br	0.0000	0.0001	0.0006	0.0001	-0.0001	0.0000	0.0001	0.0006	0.0001	-0.0001
Rb	-0.0001	0.0000	0.0005	0.0000	-0.0001	0.0000	0.0000	0.0005	0.0000	-0.0001
Sr	0.0001	0.0001	0.0006	0.0003	0.0001	0.0001	0.0001	0.0006	0.0002	0.0000
Y	-0.0001	0.0000	0.0007	0.0000	-0.0001	0.0000	0.0001	0.0007	0.0000	-0.0001
Zr	0.0003	0.0002	0.0008	0.0005	0.0000	0.0003	0.0003	0.0008	0.0006	0.0000
Mo	0.0002	0.0002	0.0015	0.0005	0.0000	0.0001	0.0002	0.0015	0.0006	0.0000
Pd	0.0001	0.0002	0.0043	0.0004	0.0000	0.0002	0.0004	0.0042	0.0010	0.0000
Ag	-0.0006	0.0005	0.0050	0.0001	-0.0012	-0.0005	0.0006	0.0049	0.0000	-0.0012
Cd	-0.0004	0.0005	0.0051	0.0004	-0.0007	-0.0003	0.0005	0.0050	0.0004	-0.0007
In	-0.0007	0.0000	0.0063	-0.0007	-0.0007	-0.0007	0.0000	0.0061	-0.0007	-0.0007
Sn	0.0009	0.0007	0.0080	0.0018	0.0000	0.0006	0.0005	0.0079	0.0010	0.0000
Sb	0.0008	0.0007	0.0093	0.0019	0.0001	0.0007	0.0007	0.0091	0.0016	0.0000
Ba	-0.0128	0.0007	0.0343	-0.0115	-0.0132	-0.0089	0.0060	0.0336	-0.0004	-0.0132
La	-0.0045	0.0045	0.0455	-0.0016	-0.0123	-0.0065	0.0063	0.0447	0.0032	-0.0133
Au	-0.0001	0.0002	0.0017	0.0002	-0.0002	-0.0002	0.0000	0.0016	-0.0002	-0.0002
Hg	-0.0002	0.0000	0.0014	-0.0002	-0.0002	-0.0002	0.0000	0.0013	-0.0002	-0.0002
Ti	-0.0002	0.0001	0.0013	-0.0001	-0.0002	-0.0002	0.0000	0.0013	-0.0001	-0.0002
Pb	0.0006	0.0002	0.0017	0.0009	0.0004	0.0001	0.0001	0.0016	0.0003	0.0000
U	0.0000	0.0001	0.0013	0.0002	0.0000	0.0000	0.0001	0.0012	0.0002	0.0000

**Table 9. Statistics for CNG and RFG Dodge Caravans for US06 PM
Chemical Species Emission Rates (mg/mi)**

Species	CNG Dodge Caravans					RFG Dodge Caravans				
	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.
Organic Carbon	4.2170	3.5173	0.4475	6.7041	1.7299	0.9517	0.4863	0.1429	1.2955	0.6078
Elemental Carbon	1.3191	0.4662	0.1314	1.6487	0.9894	1.9788	2.3408	0.1972	3.6341	0.3236
Total Carbon	5.5361	3.9834	0.5510	8.3528	2.7194	2.9305	2.8272	0.3155	4.9296	0.9314
NO ₃ ⁻	0.0408	0.0120	0.0146	0.0493	0.0323	0.0697	0.1033	0.0255	0.1428	-0.0033
SO ₄ ²⁻	0.0417	0.0038	0.0135	0.0444	0.0390	0.1552	0.1632	0.0282	0.2706	0.0397
Cl ⁻	-0.0017	0.0009	0.0124	-0.0011	-0.0023	0.0371	0.0328	0.0234	0.0603	0.0139
NH ₄ ⁺	0.0501	0.0277	0.0135	0.0697	0.0305	0.0781	0.0786	0.0242	0.1337	0.0225
Na	-0.0063	0.0000	0.0284	-0.0063	-0.0063	-0.0063	0.0000	0.0732	-0.0063	-0.0063
Mg	0.0373	0.0022	0.0092	0.0389	0.0357	0.1115	0.0432	0.0160	0.1421	0.0810
Al	0.0620	0.0297	0.0070	0.0830	0.0409	0.0350	0.0424	0.0073	0.0650	0.0050
Si	0.3351	0.2194	0.0301	0.4903	0.1800	0.1373	0.1165	0.0131	0.2196	0.0549
P	0.0206	0.0104	0.0022	0.0280	0.0132	0.1084	0.0474	0.0102	0.1419	0.0748
S	0.0607	0.0189	0.0055	0.0740	0.0474	0.1234	0.0890	0.0113	0.1863	0.0604
Cl	0.0211	0.0088	0.0034	0.0273	0.0149	0.0508	0.0055	0.0060	0.0546	0.0469
K	0.0194	0.0140	0.0028	0.0294	0.0095	0.0036	0.0046	0.0026	0.0069	0.0003
Ca	0.0203	0.0076	0.0025	0.0257	0.0150	0.1005	0.0991	0.0095	0.1706	0.0305
Ti	0.0045	0.0039	0.0118	0.0072	0.0017	0.0004	0.0006	0.0216	0.0008	0.0000
V	0.0013	0.0013	0.0055	0.0023	0.0004	0.0002	0.0003	0.0091	0.0004	0.0000
Cr	0.0082	0.0062	0.0018	0.0126	0.0038	0.0063	0.0062	0.0019	0.0107	0.0020
Mn	0.0014	0.0008	0.0009	0.0020	0.0008	0.0025	0.0023	0.0012	0.0041	0.0009
Fe	0.1559	0.0864	0.0140	0.2169	0.0948	0.3782	0.4323	0.0339	0.6838	0.0725
Co	0.0000	0.0000	0.0026	0.0000	0.0000	0.0000	0.0000	0.0063	0.0000	0.0000
Ni	0.0034	0.0008	0.0006	0.0040	0.0029	0.0063	0.0039	0.0009	0.0091	0.0036
Cu	0.0019	0.0001	0.0006	0.0020	0.0018	0.0189	0.0004	0.0019	0.0192	0.0187
Zn	0.0320	0.0162	0.0029	0.0434	0.0206	0.1602	0.0455	0.0144	0.1924	0.1281
Ga	-0.0002	0.0000	0.0010	-0.0002	-0.0002	-0.0002	0.0000	0.0018	-0.0002	-0.0002
As	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0000	0.0024	0.0000	0.0000
Se	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000	0.0010	0.0000	0.0000
Br	0.0007	0.0000	0.0005	0.0008	0.0007	0.0018	0.0020	0.0007	0.0033	0.0004
Rb	0.0001	0.0000	0.0005	0.0001	0.0001	-0.0001	0.0000	0.0009	-0.0001	-0.0001
Sr	0.0001	0.0001	0.0005	0.0002	0.0001	0.0001	0.0000	0.0010	0.0001	0.0001
Y	-0.0001	0.0000	0.0007	-0.0001	-0.0001	0.0001	0.0002	0.0012	0.0002	-0.0001
Zr	0.0020	0.0015	0.0008	0.0031	0.0010	0.0006	0.0006	0.0014	0.0011	0.0001
Mo	0.0006	0.0003	0.0014	0.0008	0.0004	0.0011	0.0005	0.0025	0.0015	0.0008
Pd	0.0017	0.0023	0.0040	0.0033	0.0000	0.0002	0.0003	0.0073	0.0005	0.0000
Ag	-0.0012	0.0000	0.0047	-0.0012	-0.0012	0.0007	0.0024	0.0085	0.0024	-0.0009
Cd	-0.0007	0.0001	0.0048	-0.0006	-0.0007	0.0003	0.0002	0.0087	0.0004	0.0001
In	-0.0007	0.0000	0.0058	-0.0007	-0.0007	0.0006	0.0018	0.0104	0.0019	-0.0007
Sn	0.0007	0.0002	0.0075	0.0008	0.0005	0.0055	0.0071	0.0135	0.0105	0.0006
Sb	0.0010	0.0006	0.0087	0.0014	0.0005	0.0040	0.0023	0.0151	0.0056	0.0024
Ba	-0.0078	0.0006	0.0320	-0.0074	-0.0082	0.0145	0.0391	0.0583	0.0422	-0.0132
La	-0.0133	0.0000	0.0426	-0.0133	-0.0133	-0.0133	0.0000	0.0760	-0.0133	-0.0133
Au	0.0000	0.0000	0.0021	0.0000	-0.0001	0.0002	0.0006	0.0067	0.0006	-0.0002
Hg	-0.0002	0.0000	0.0013	-0.0002	-0.0002	-0.0002	0.0000	0.0024	-0.0002	-0.0002
Pb	-0.0002	0.0000	0.0012	-0.0002	-0.0002	-0.0002	0.0000	0.0022	-0.0002	-0.0002
Pb	0.0006	0.0000	0.0015	0.0007	0.0006	0.0061	0.0061	0.0019	0.0105	0.0018
U	0.0001	0.0000	0.0012	0.0001	0.0000	0.0000	0.0000	0.0021	0.0000	0.0000

**Table 10. Statistics for M85 and RFG Ford Taurus for US06 PM
Chemical Species Emission Rates (mg/mi)**

Species	M85 Ford Tauruses					RFG Ford Tauruses				
	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.	Avg.	St. Dev.	Avg. Uncert.	Max.	Min.
Organic Carbon	0.3797	0.0207	0.1178	0.3944	0.3650	0.2515	0.1039	0.1077	0.3250	0.1781
Elemental Carbon	0.4435	0.2839	0.0472	0.6442	0.2428	0.7554	0.3951	0.0728	1.0348	0.4760
Total Carbon	0.8232	0.2631	0.1404	1.0093	0.6371	1.0069	0.2913	0.1491	1.2129	0.8009
NO ₃ ⁻	-0.0081	0.0038	0.0136	-0.0054	-0.0107	-0.0151	0.0057	0.0136	-0.0111	-0.0191
SO ₄ ²⁻	0.0415	0.0546	0.0144	0.0802	0.0029	0.0035	0.0175	0.0130	0.0158	-0.0089
Cl ⁻	0.0852	0.0891	0.0182	0.1482	0.0223	-0.0087	0.0027	0.0126	-0.0068	-0.0105
NH ₄ ⁺	0.0814	0.0047	0.0202	0.0847	0.0781	0.0087	0.0100	0.0130	0.0158	0.0016
Na	-0.0044	0.0027	0.0284	-0.0025	-0.0063	-0.0063	0.0000	0.0248	-0.0063	-0.0063
Mg	0.0016	0.0090	0.0101	0.0080	-0.0048	0.0008	0.0011	0.0097	0.0016	0.0000
Al	-0.0027	0.0015	0.0063	-0.0017	-0.0037	-0.0025	0.0018	0.0054	-0.0013	-0.0037
Si	0.5004	0.1144	0.0449	0.5812	0.4195	0.3646	0.1809	0.0327	0.4925	0.2368
P	0.0105	0.0022	0.0016	0.0121	0.0089	0.0045	0.0027	0.0012	0.0064	0.0026
S	0.0387	0.0413	0.0037	0.0680	0.0095	0.0105	0.0023	0.0013	0.0122	0.0089
Cl	0.1386	0.1031	0.0129	0.2114	0.0657	0.0049	0.0004	0.0027	0.0052	0.0046
K	0.0000	0.0009	0.0022	0.0007	-0.0007	-0.0009	0.0003	0.0024	-0.0007	-0.0011
Ca	0.0289	0.0071	0.0031	0.0339	0.0239	0.0198	0.0071	0.0024	0.0248	0.0148
Ti	0.0000	0.0000	0.0124	0.0000	0.0000	0.0006	0.0008	0.0123	0.0012	0.0000
V	0.0000	0.0000	0.0060	0.0000	0.0000	0.0000	0.0000	0.0059	0.0000	0.0000
Cr	0.0001	0.0001	0.0018	0.0002	0.0000	0.0001	0.0002	0.0017	0.0002	0.0000
Mn	0.0000	0.0000	0.0010	0.0000	-0.0001	-0.0001	0.0000	0.0010	-0.0001	-0.0001
Fe	0.0290	0.0245	0.0027	0.0463	0.0116	0.0184	0.0182	0.0018	0.0313	0.0055
Co	0.0001	0.0000	0.0008	0.0001	0.0001	0.0000	0.0000	0.0007	0.0000	0.0000
Ni	0.0002	0.0002	0.0006	0.0004	0.0001	0.0001	0.0001	0.0006	0.0001	0.0000
Cu	0.0021	0.0025	0.0006	0.0039	0.0003	0.0011	0.0011	0.0006	0.0018	0.0003
Zn	0.0148	0.0032	0.0014	0.0170	0.0125	0.0065	0.0034	0.0008	0.0089	0.0040
Ga	-0.0001	0.0001	0.0010	-0.0001	-0.0002	-0.0002	0.0000	0.0010	-0.0002	-0.0002
As	0.0000	0.0000	0.0011	0.0000	0.0000	0.0000	0.0001	0.0011	0.0000	0.0000
Se	0.0000	0.0000	0.0006	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000	0.0000
Br	0.0013	0.0004	0.0006	0.0016	0.0010	0.0002	0.0001	0.0005	0.0003	0.0001
Rb	-0.0001	0.0000	0.0005	-0.0001	-0.0001	0.0000	0.0000	0.0005	0.0000	-0.0001
Sr	0.0002	0.0002	0.0005	0.0003	0.0001	0.0002	0.0001	0.0005	0.0003	0.0001
Y	-0.0001	0.0000	0.0007	-0.0001	-0.0001	-0.0001	0.0000	0.0007	0.0000	-0.0001
Zr	0.0002	0.0003	0.0008	0.0005	0.0000	0.0001	0.0002	0.0008	0.0003	0.0000
Mo	0.0001	0.0001	0.0014	0.0001	0.0000	0.0001	0.0001	0.0014	0.0001	0.0000
Pd	0.0001	0.0001	0.0041	0.0001	0.0000	0.0000	0.0000	0.0041	0.0000	0.0000
Ag	-0.0008	0.0001	0.0048	-0.0007	-0.0008	-0.0011	0.0000	0.0047	-0.0011	-0.0011
Cd	-0.0003	0.0006	0.0049	0.0002	-0.0007	-0.0003	0.0006	0.0048	0.0001	-0.0007
In	-0.0007	0.0000	0.0059	-0.0007	-0.0007	-0.0002	0.0007	0.0059	0.0003	-0.0007
Sn	0.0020	0.0012	0.0074	0.0029	0.0011	0.0005	0.0007	0.0076	0.0010	0.0000
Sb	0.0013	0.0004	0.0088	0.0016	0.0010	0.0004	0.0006	0.0088	0.0008	0.0000
Ba	-0.0008	0.0091	0.0315	0.0056	-0.0073	-0.0060	0.0102	0.0314	0.0013	-0.0132
La	-0.0028	0.0008	0.0431	-0.0023	-0.0034	-0.0038	0.0059	0.0429	0.0004	-0.0080
Au	-0.0002	0.0000	0.0017	-0.0002	-0.0002	-0.0002	0.0000	0.0016	-0.0002	-0.0002
Hg	-0.0002	0.0001	0.0013	-0.0001	-0.0002	-0.0002	0.0001	0.0013	-0.0001	-0.0002
Ti	-0.0002	0.0000	0.0012	-0.0002	-0.0002	-0.0002	0.0000	0.0012	-0.0002	-0.0002
Pb	0.0008	0.0006	0.0016	0.0012	0.0004	0.0002	0.0002	0.0016	0.0003	0.0001
U	0.0000	0.0000	0.0012	0.0000	0.0000	0.0000	0.0000	0.0012	0.0000	0.0000

It should be noted that the low emissions levels and the large sample-to-sample variability (as indicated by the large standard deviations) make it difficult to differentiate between the species profiles for different vehicle/fuel combinations or to compare the US06 and FTP. It should also be noted that mass identified from the chemical analyses was generally less than that obtained from the gravimetric measurements, as shown in Appendices F and G. This could be because of the higher blank levels for the chemical analysis and organic carbon measurements, the fact that not all species that contribute to the particle composition are measured, or the difficulties in determining total carbon based on TOR from a small section of the filter, as has been observed in previous studies (Sagebiel et al., 1997; Watson et al., 1994).

4.2 PAH, Hopane, and Sterane Emission Results

Total PAH emission rates were obtained for each fuel/vehicle group. The FTP PAH emission results are presented in Table 11 and Figure 11 for the CNG and RFG Dodge Caravans and in Table 12 and Figure 12 for the M85 and RFG Ford Tauruses. These results were obtained by grouping samples for all five vehicles in each vehicle/fuel group into a single sample for extraction and subsequent analysis. The US06 emission results for PAHs are presented in Table 13 and Figure 13 for the CNG and RFG Dodge Caravans and in Table 14 and Figure 14 for the M85 and RFG Ford Tauruses. These results were obtained by grouping samples from two of the vehicles in each group into a single sample for extraction and subsequent analysis. The emission rates are corrected for the contribution of trace species detected in the dilution tunnel, and as a result, include some negative values. For Tables 11-14, chemical components whose concentrations are at least twice the average uncertainty are shown in bold.

PAH emissions were highest for the RFG fueled vehicles. Total FTP PAH emissions rates were 1,142.0 $\mu\text{g}/\text{mi}$ for the RFG Dodge Caravans and 352.5 $\mu\text{g}/\text{mi}$ for the RFG Ford Tauruses. Total PAH emissions were lower over the US06 with an emission rate of 965.1 $\mu\text{g}/\text{mi}$ for the RFG Dodge Caravans and 203.1 $\mu\text{g}/\text{mi}$ for the RFG Ford Tauruses. These levels are comparable to those reported by Siegel et al. (1994) for a normal-emitting vehicle, but are slightly less than those reported by Sagebiel et al. (1997) for high-emitting gasoline vehicles in Nevada. These levels are also slightly higher than those measured by Whitney (1997), since emission rates of semi-volatile PAHs such as naphthalenes, methylnaphthalenes and dimethylnaphthalenes were not quantified in that study. The distribution of PAHs for the gasoline vehicles is similar to that reported previously (Siegel et al., 1994; Sagebiel et al., 1997) with naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, and dimethylnaphthalenes being the primary constituents.

Total PAH emission rates for the M85 Ford Tauruses were lower for the FTP (160.6 $\mu\text{g}/\text{mi}$) and considerably lower for the US06 (21.7 $\mu\text{g}/\text{mi}$) compared with the RFG Ford Tauruses. Naphthalene and methylnaphthalenes were the most prominent PAHs for the M85 vehicles. Other PAHs detected at levels below 10 $\mu\text{g}/\text{mi}$ include biphenyl, phenanthrene, C-methylfluorene, anthracene and pyrene. Total FTP PAH emissions for the CNG vehicles were considerably lower (50.5 $\mu\text{g}/\text{mi}$) than those for either the RFG or M85 vehicles. For the US06, total PAH emissions for the CNG vehicles (31.6 $\mu\text{g}/\text{mi}$) were lower than those for the RFG vehicles but comparable to those for the M85 vehicles. Unlike the RFG and M85 vehicles, naphthalenes, 2-

methylnaphthalene, and 1-methylnaphthalene were not detected for the CNG vehicles. The only PAHs detected at levels greater than 3 µg/mi for CNG on both the FTP and US06 cycles were pyrene, fluoranthene, phenanthrene, and C-methylfluorene.

Analyses were also conducted for hopane and sterane emissions using the same sample groupings used for the PAH analyses. No hopane or sterane compounds were measured above detectable levels, however, for any of the vehicle/fuel/driving-cycle groups. Because hopanes and steranes are primarily oil tracers, this indicates that none of the test vehicles were excessive oil burners. It should be noted, however, that some elements that can be attributed to oil sources were identified in the XRF analysis (Mg, P, Ca, and Zn).

Figure 11. PAH Mass Emission Rates for CNG/RFG Dodge Caravans for FTP

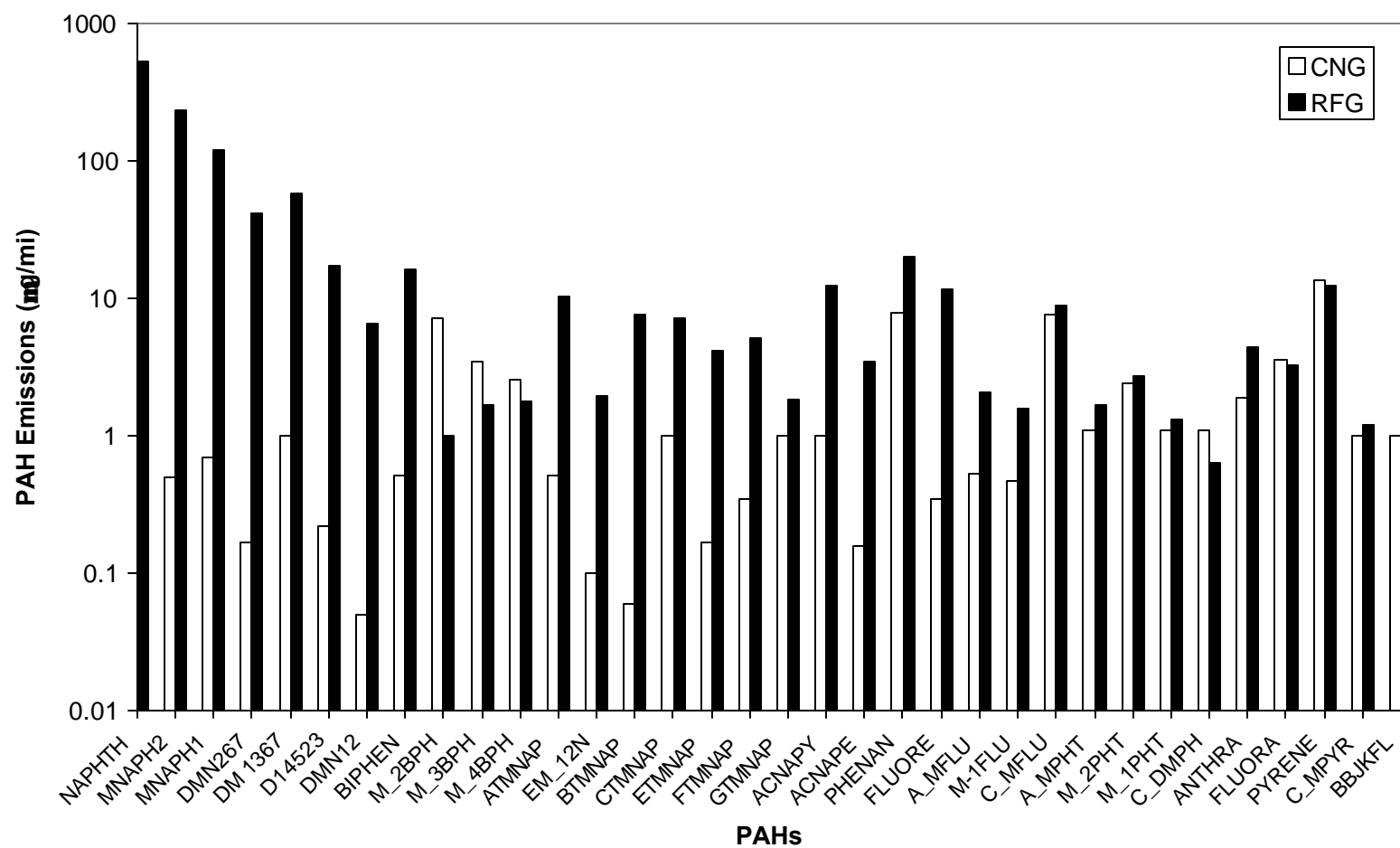


Figure 12. PAH Mass Emission Rates for M85/RFG Ford Tauruses for FTP

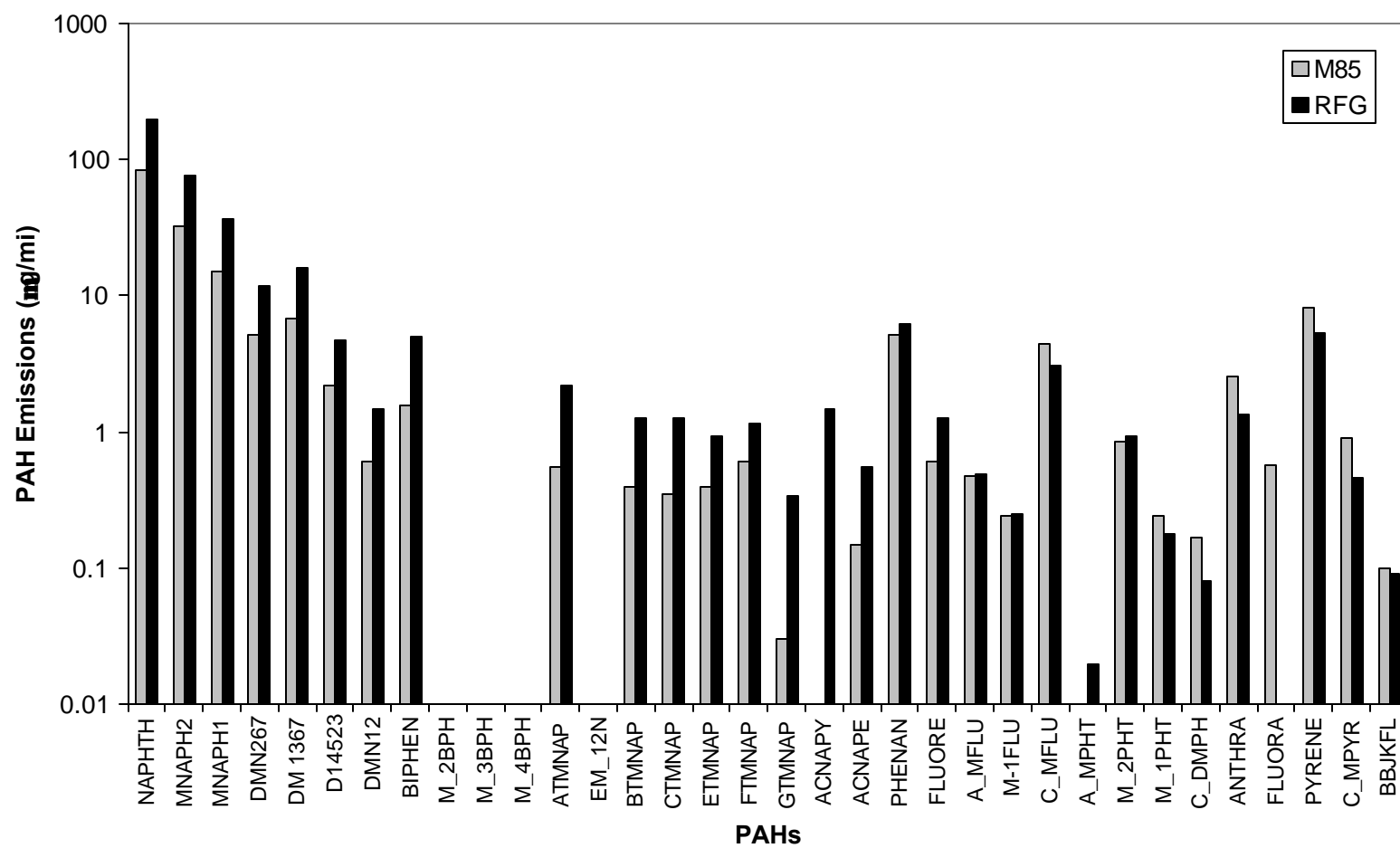


Figure 13. PAH Mass Emission Rates for CNG/RFG Dodge Caravans for US06

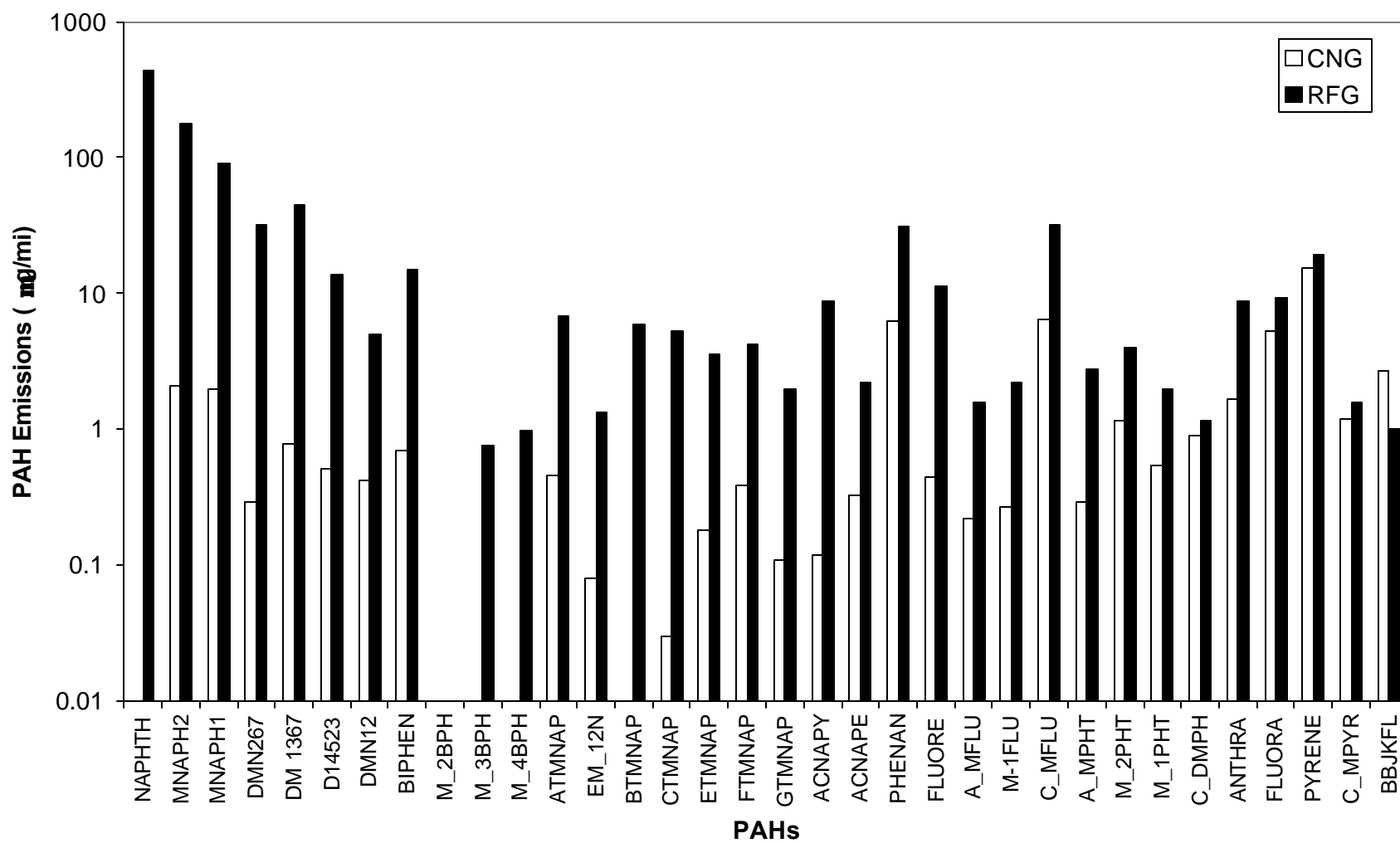


Figure 14. PAH Mass Emission Rates for M85/RFG Ford Tauruses for US06

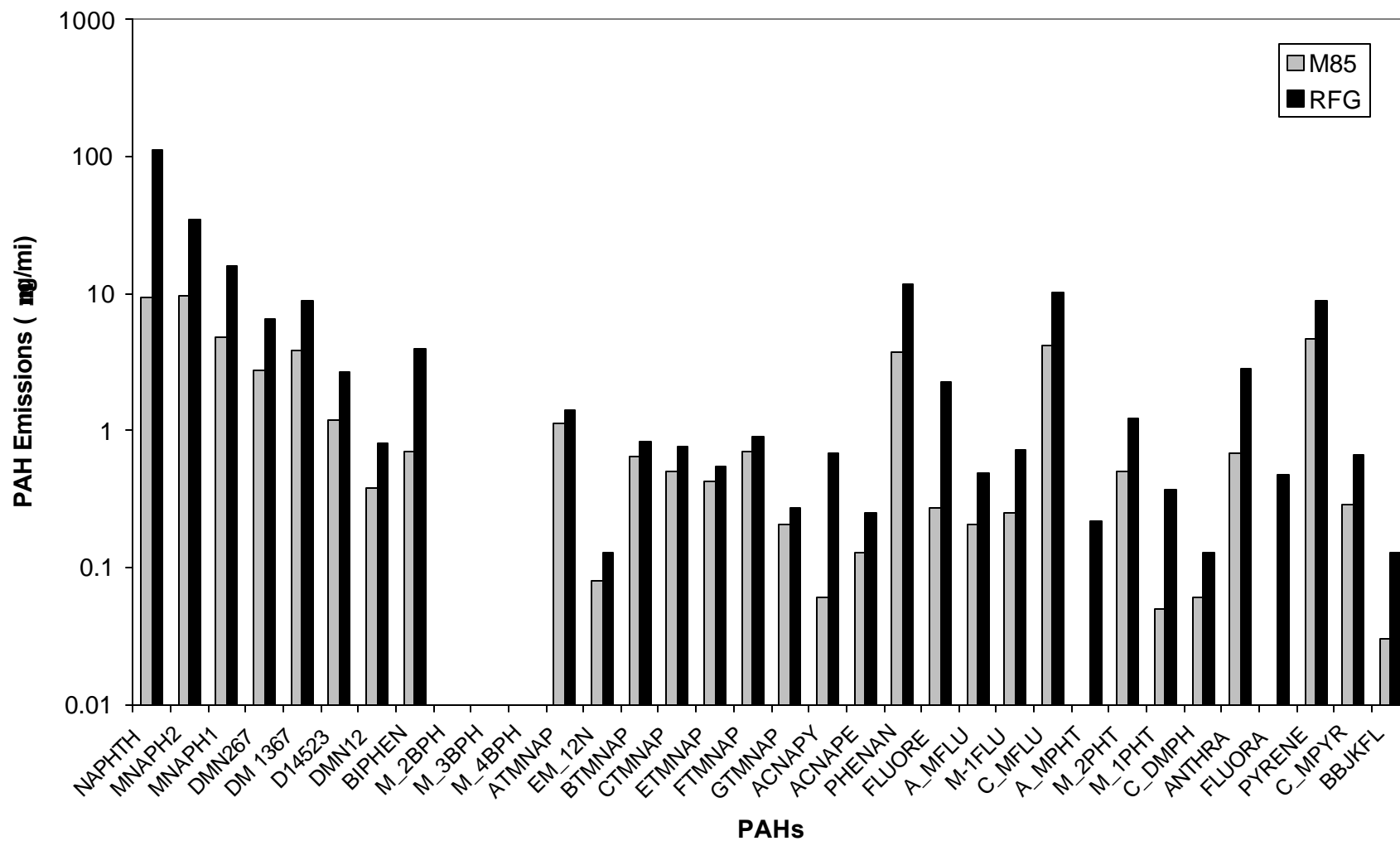


Table 11. Statistics for CNG and RFG Dodge Caravans for FTP PAH Emissions (µg/mi)

	CNG Dodge Caravans				RFG Dodge Caravans		
Naphthalene	-2.51	+/-	2.02		531.99	+/-	55.89
2-Methylnaphthalene	0.51	+/-	1.99		232.29	+/-	24.52
1-Methylnaphthalene	0.71	+/-	1.07		120.31	+/-	12.77
2,6+2,7-Dimethylnaphthalene	0.17	+/-	2.70		41.46	+/-	5.17
1,7+1,3+1,6-Dimethylnaphthalene	-0.31	+/-	3.59		57.55	+/-	7.03
2,3+1,4+1,5-Dimethylnaphthalene	0.22	+/-	5.12		17.51	+/-	5.42
1,2-Dimethylnaphthalene	0.05	+/-	3.14		6.56	+/-	3.22
1,8-Dimethylnaphthalene	0.00	+/-	2.59		0.09	+/-	2.58
Biphenyl	0.52	+/-	0.62		16.33	+/-	1.85
2-Methylbiphenyl	7.23	+/-	1.82		-13.65	+/-	1.67
3-Methylbiphenyl	3.54	+/-	0.84		1.67	+/-	0.73
4-Methylbiphenyl	2.55	+/-	0.68		1.80	+/-	0.62
A-Trimethylnaphthalene	0.52	+/-	0.48		10.40	+/-	1.23
1-Ethyl-2-methylnaphthalene	0.10	+/-	0.48		1.97	+/-	0.54
B-Trimethylnaphthalene	0.06	+/-	0.48		7.79	+/-	1.04
C-Trimethylnaphthalene	-0.03	+/-	0.48		7.15	+/-	0.95
2-Ethyl-1-methylnaphthalene	-0.03	+/-	0.48		0.19	+/-	0.48
E-Trimethylnaphthalene	0.17	+/-	0.49		4.22	+/-	0.78
F-Trimethylnaphthalene	0.35	+/-	0.48		5.15	+/-	0.76
G-Trimethylnaphthalene	-0.06	+/-	0.49		1.88	+/-	0.68
H-Trimethylnaphthalene	-0.11	+/-	0.48		0.39	+/-	0.48
1,2,8-Trimethylnaphthalene	0.02	+/-	0.48		0.35	+/-	0.52
Acenaphthylene	-0.15	+/-	3.11		12.64	+/-	3.44
Acenaphthene	0.16	+/-	1.40		3.47	+/-	1.45
Phenanthrene	7.87	+/-	1.13		20.26	+/-	2.32
Fluorene	0.35	+/-	0.56		11.61	+/-	1.43
A-Methylfluorene	0.53	+/-	0.50		2.07	+/-	0.59
1-Methylfluorene	0.47	+/-	0.49		1.60	+/-	0.54
B-Methylfluorene	-1.96	+/-	0.57		-1.53	+/-	0.56
C-Methylfluorene	7.77	+/-	1.20		9.05	+/-	1.35
A-Methylphenanthrene	1.12	+/-	0.57		1.70	+/-	0.63
2-Methylphenanthrene	2.43	+/-	0.56		2.75	+/-	0.58
B-Methylphenanthrene	-0.31	+/-	0.48		-0.20	+/-	0.48
C-Methylphenanthrene	0.57	+/-	0.53		0.43	+/-	0.52
1-Methylphenanthrene	1.12	+/-	0.51		1.31	+/-	0.51
3,6-Dimethylphenanthrene	0.24	+/-	0.49		0.31	+/-	0.49
A-Dimethylphenanthrene	0.65	+/-	0.49		0.66	+/-	0.49
B-Dimethylphenanthrene	0.05	+/-	0.48		-0.10	+/-	0.48
C-Dimethylphenanthrene	1.11	+/-	0.52		0.64	+/-	0.49
1,7-Dimethylphenanthrene	0.40	+/-	0.48		0.37	+/-	0.48
D-Dimethylphenanthrene	0.27	+/-	0.48		0.14	+/-	0.48
E-Dimethylphenanthrene	-0.31	+/-	0.35		-0.34	+/-	0.34
Anthracene	1.93	+/-	0.57		4.49	+/-	0.83
9-Methylanthracene	-5.63	+/-	1.10		-5.55	+/-	1.10
Fluoranthene	3.57	+/-	1.00		3.34	+/-	0.98
Pyrene	13.62	+/-	1.54		12.60	+/-	1.44
A-Methylpyrene	-0.24	+/-	0.48		-0.18	+/-	0.48
B-Methylpyrene	0.03	+/-	0.48		0.04	+/-	0.48
C-Methylpyrene	1.00	+/-	0.49		1.22	+/-	0.50
D-Methylpyrene	0.17	+/-	0.48		0.45	+/-	0.48
E-Methylpyrene	0.39	+/-	0.48		0.34	+/-	0.48
F-Methylpyrene	0.27	+/-	0.68		0.30	+/-	0.68
Retene	0.00	+/-	0.95		-0.01	+/-	0.95
Benzonaphthothiophene	-0.01	+/-	1.40		0.00	+/-	1.39
Benz(a)anthracene	0.10	+/-	0.50		0.44	+/-	0.49
7-Methylbenz[a]anthracene	-0.14	+/-	0.71		-0.15	+/-	0.71
Chrysene	0.08	+/-	0.79		0.49	+/-	0.79
Benzo(b+j+k)fluoranthene	-0.01	+/-	0.48		1.54	+/-	0.55
Benzo(e)pyrene	0.00	+/-	1.53		0.42	+/-	1.53
Benzo(a)pyrene	-0.02	+/-	0.50		0.55	+/-	0.49
7-Methylbenzo[a]pyrene	-0.11	+/-	1.29		-0.10	+/-	1.29
Indeno[1,2,3-cd]pyrene	-0.01	+/-	1.87		0.41	+/-	1.87
Dibenz(ah+ac)anthracene	-0.03	+/-	0.97		-0.02	+/-	0.96
Benzo(b)chrysene	-0.09	+/-	1.67		-0.07	+/-	1.66
Benzo(ghi)perylene	-0.45	+/-	0.54		0.53	+/-	0.54
Coronene	0.02	+/-	0.05		0.68	+/-	0.17
Total	50.50				1142.00		

Table 12. Statistics for M85 and RFG FFV Ford Taurus for FTP PAH Emissions (µg/mi)

	M85 Ford Taurus				RFG Ford Taurus		
Naphthalene	84.38	+/-	9.38		195.27	+/-	20.80
2-Methylnaphthalene	32.61	+/-	4.01		75.54	+/-	8.23
1-Methylnaphthalene	15.25	+/-	1.95		37.21	+/-	4.10
2,6+2,7-Dimethylnaphthalene	5.14	+/-	2.76		11.86	+/-	2.98
1,7+1,3+1,6-Dimethylnaphthalene	6.77	+/-	3.66		16.05	+/-	3.97
2,3+1,4+1,5-Dimethylnaphthalene	2.23	+/-	5.12		4.68	+/-	5.12
1,2-Dimethylnaphthalene	0.61	+/-	3.14		1.49	+/-	3.13
1,8-Dimethylnaphthalene	0.00	+/-	2.59		1.32	+/-	2.67
Biphenyl	1.59	+/-	0.64		4.95	+/-	0.82
2-Methylbiphenyl	-5.31	+/-	1.33		-9.96	+/-	1.45
3-Methylbiphenyl	-1.07	+/-	0.66		-2.09	+/-	0.65
4-Methylbiphenyl	-0.42	+/-	0.55		-0.64	+/-	0.54
A-Trimethylnaphthalene	0.56	+/-	0.48		2.17	+/-	0.53
1-Ethyl-2-methylnaphthalene	-0.03	+/-	0.48		0.28	+/-	0.48
B-Trimethylnaphthalene	0.39	+/-	0.49		1.25	+/-	0.51
C-Trimethylnaphthalene	0.35	+/-	0.48		1.27	+/-	0.51
2-Ethyl-1-methylnaphthalene	0.07	+/-	0.48		0.08	+/-	0.48
E-Trimethylnaphthalene	0.40	+/-	0.49		0.92	+/-	0.50
F-Trimethylnaphthalene	0.61	+/-	0.48		1.17	+/-	0.50
G-Trimethylnaphthalene	0.03	+/-	0.48		0.34	+/-	0.49
H-Trimethylnaphthalene	-0.09	+/-	0.48		-0.09	+/-	0.48
1,2,8-Trimethylnaphthalene	-0.07	+/-	0.48		0.00	+/-	0.48
Acenaphthylene	-0.18	+/-	3.10		1.48	+/-	3.10
Acenaphthene	0.15	+/-	1.40		0.55	+/-	1.40
Phenanthrene	5.22	+/-	0.93		6.13	+/-	0.99
Fluorene	0.61	+/-	0.56		1.28	+/-	0.58
A-Methylfluorene	0.47	+/-	0.49		0.49	+/-	0.49
1-Methylfluorene	0.24	+/-	0.48		0.25	+/-	0.48
B-Methylfluorene	-2.01	+/-	0.57		-1.99	+/-	0.57
C-Methylfluorene	4.38	+/-	0.81		3.09	+/-	0.67
A-Methylphenanthrene	-0.13	+/-	0.49		0.02	+/-	0.50
2-Methylphenanthrene	0.86	+/-	0.49		0.94	+/-	0.49
B-Methylphenanthrene	-0.36	+/-	0.48		-0.36	+/-	0.48
C-Methylphenanthrene	-0.17	+/-	0.49		-0.25	+/-	0.48
1-Methylphenanthrene	0.24	+/-	0.48		0.18	+/-	0.48
3,6-Dimethylphenanthrene	-0.10	+/-	0.48		-0.10	+/-	0.48
A-Dimethylphenanthrene	0.18	+/-	0.48		0.15	+/-	0.48
B-Dimethylphenanthrene	-0.21	+/-	0.48		0.28	+/-	0.48
C-Dimethylphenanthrene	0.17	+/-	0.48		0.08	+/-	0.48
1,7-Dimethylphenanthrene	0.04	+/-	0.48		-0.04	+/-	0.48
D-Dimethylphenanthrene	0.02	+/-	0.48		-0.04	+/-	0.48
E-Dimethylphenanthrene	-0.57	+/-	0.35		-0.60	+/-	0.34
Anthracene	2.53	+/-	0.61		1.35	+/-	0.52
9-Methylanthracene	-5.00	+/-	1.09		-5.61	+/-	1.10
Fluoranthene	0.57	+/-	0.82		-3.05	+/-	0.76
Pyrene	8.10	+/-	1.02		5.33	+/-	0.78
A-Methylpyrene	-0.08	+/-	0.48		-0.21	+/-	0.48
B-Methylpyrene	0.00	+/-	0.48		-0.22	+/-	0.48
C-Methylpyrene	0.90	+/-	0.49		0.46	+/-	0.48
D-Methylpyrene	0.12	+/-	0.48		0.03	+/-	0.48
E-Methylpyrene	0.06	+/-	0.48		0.09	+/-	0.48
F-Methylpyrene	0.08	+/-	0.68		0.06	+/-	0.68
Retene	0.02	+/-	0.95		-0.01	+/-	0.95
Benzonaphthothiophene	0.05	+/-	1.40		-0.01	+/-	1.39
Benz(a)anthracene	0.41	+/-	0.51		0.15	+/-	0.48
7-Methylbenz[a]anthracene	0.03	+/-	0.72		-0.16	+/-	0.71
Chrysene	0.21	+/-	0.79		0.05	+/-	0.78
Benzo(b+j+k)fluoranthene	0.10	+/-	0.48		0.09	+/-	0.48
Benzo(e)pyrene	0.03	+/-	1.53		0.01	+/-	1.53
Benzo(a)pyrene	0.19	+/-	0.50		0.16	+/-	0.48
7-Methylbenzo[a]pyrene	-0.11	+/-	1.29		-0.11	+/-	1.29
Indeno[1,2,3-cd]pyrene	0.01	+/-	1.87		0.00	+/-	1.87
Dibenz(ah+ac)anthracene	-0.03	+/-	0.97		-0.03	+/-	0.95
Benzo(b)chrysene	-0.10	+/-	1.67		-0.10	+/-	1.66
Benzo(ghi)perylene	-0.40	+/-	0.54		-0.40	+/-	0.52
Coronene	0.07	+/-	0.05		0.04	+/-	0.02
Total	160.58				352.52		

Table 13. Statistics for CNG and RFG Dodge Caravans for USO6 PAH Emissions (µg/mi)

	CNG Dodge Caravans				RFG Dodge Caravans		
Naphthalene	-4.27	+/-	1.94		431.97	+/-	45.47
2-Methylnaphthalene	2.10	+/-	2.02		177.02	+/-	18.75
1-Methylnaphthalene	2.00	+/-	1.10		89.26	+/-	9.51
2,6+2,7-Dimethylnaphthalene	0.29	+/-	2.72		31.63	+/-	4.32
1,7+1,3+1,6-Dimethylnaphthalene	0.77	+/-	3.62		44.49	+/-	5.91
2,3+1,4+1,5-Dimethylnaphthalene	0.51	+/-	5.17		13.84	+/-	5.33
1,2-Dimethylnaphthalene	0.42	+/-	3.17		5.07	+/-	3.20
1,8-Dimethylnaphthalene	0.04	+/-	2.62		0.46	+/-	2.61
Biphenyl	0.69	+/-	0.63		15.08	+/-	1.73
2-Methylbiphenyl	-9.57	+/-	1.45		-13.65	+/-	1.67
3-Methylbiphenyl	-2.55	+/-	0.67		0.76	+/-	0.69
4-Methylbiphenyl	-0.75	+/-	0.55		0.98	+/-	0.58
A-Trimethylnaphthalene	0.46	+/-	0.49		6.90	+/-	0.89
1-Ethyl-2-methylnaphthalene	0.08	+/-	0.48		1.33	+/-	0.51
B-Trimethylnaphthalene	-0.04	+/-	0.49		5.87	+/-	0.85
C-Trimethylnaphthalene	0.03	+/-	0.49		5.35	+/-	0.78
2-Ethyl-1-methylnaphthalene	0.01	+/-	0.48		0.12	+/-	0.48
E-Trimethylnaphthalene	0.18	+/-	0.49		3.59	+/-	0.71
F-Trimethylnaphthalene	0.39	+/-	0.49		4.27	+/-	0.69
G-Trimethylnaphthalene	0.11	+/-	0.49		1.96	+/-	0.70
H-Trimethylnaphthalene	-0.06	+/-	0.48		0.31	+/-	0.48
1,2,8-Trimethylnaphthalene	0.01	+/-	0.49		0.34	+/-	0.52
Acenaphthylene	0.12	+/-	3.14		8.68	+/-	3.27
Acenaphthene	0.33	+/-	1.41		2.24	+/-	1.43
Phenanthrene	6.24	+/-	1.00		31.11	+/-	3.45
Fluorene	0.45	+/-	0.57		11.18	+/-	1.38
A-Methylfluorene	0.22	+/-	0.49		1.59	+/-	0.55
1-Methylfluorene	0.27	+/-	0.49		2.20	+/-	0.60
B-Methylfluorene	-2.02	+/-	0.57		-1.51	+/-	0.56
C-Methylfluorene	6.42	+/-	1.03		31.65	+/-	4.24
A-Methylphenanthrene	0.29	+/-	0.51		2.74	+/-	0.75
2-Methylphenanthrene	1.15	+/-	0.50		4.03	+/-	0.68
B-Methylphenanthrene	-0.36	+/-	0.48		-0.35	+/-	0.48
C-Methylphenanthrene	0.15	+/-	0.50		0.94	+/-	0.57
1-Methylphenanthrene	0.54	+/-	0.49		2.00	+/-	0.55
3,6-Dimethylphenanthrene	-0.01	+/-	0.49		0.54	+/-	0.50
A-Dimethylphenanthrene	0.28	+/-	0.49		0.97	+/-	0.51
B-Dimethylphenanthrene	-0.16	+/-	0.48		0.16	+/-	0.48
C-Dimethylphenanthrene	0.91	+/-	0.51		1.17	+/-	0.52
1,7-Dimethylphenanthrene	0.27	+/-	0.49		0.51	+/-	0.48
D-Dimethylphenanthrene	0.21	+/-	0.49		0.38	+/-	0.48
E-Dimethylphenanthrene	-0.37	+/-	0.35		-0.08	+/-	0.35
Anthracene	1.69	+/-	0.55		8.82	+/-	1.41
9-Methylanthracene	-5.30	+/-	1.09		-5.22	+/-	1.09
Fluoranthene	5.25	+/-	1.13		9.28	+/-	1.48
Pyrene	15.32	+/-	1.71		19.21	+/-	2.11
A-Methylpyrene	0.45	+/-	0.49		-0.06	+/-	0.48
B-Methylpyrene	0.01	+/-	0.48		0.36	+/-	0.48
C-Methylpyrene	1.19	+/-	0.50		1.56	+/-	0.51
D-Methylpyrene	0.22	+/-	0.49		0.35	+/-	0.48
E-Methylpyrene	0.54	+/-	0.49		0.53	+/-	0.48
F-Methylpyrene	0.41	+/-	0.69		0.37	+/-	0.68
Retene	0.15	+/-	0.96		0.11	+/-	0.95
Benzonaphthothiophene	0.15	+/-	1.40		0.11	+/-	1.40
Benz(a)anthracene	0.78	+/-	0.56		0.60	+/-	0.52
7-Methylbenz[a]anthracene	-0.13	+/-	0.72		-0.16	+/-	0.71
Chrysene	1.03	+/-	0.82		0.61	+/-	0.80
Benzo(b+j+k)fluoranthene	2.69	+/-	0.67		1.01	+/-	0.51
Benzo(e)pyrene	0.85	+/-	1.54		0.35	+/-	1.53
Benzo(a)pyrene	0.11	+/-	0.55		0.12	+/-	0.50
7-Methylbenzo[a]pyrene	-0.10	+/-	1.29		-0.11	+/-	1.29
Indeno[1,2,3-cd]pyrene	0.27	+/-	1.88		0.12	+/-	1.87
Dibenz(ah+ac)anthracene	-0.01	+/-	1.01		-0.03	+/-	0.97
Benzo(b)chrysene	-0.08	+/-	1.67		-0.10	+/-	1.67
Benzo(ghi)perylene	0.06	+/-	0.60		-0.02	+/-	0.55
Coronene	0.24	+/-	0.10		0.20	+/-	0.07
Total	31.60				965.10		

Table 14. Statistics for M85 and RFG FFV Ford Taurus for USO6 PAH Emissions (µg/mi)

	M85 Ford Taurus				RFG Ford Taurus		
Naphthalene	9.34	+/-	2.40		110.81	+/-	12.07
2-Methylnaphthalene	9.71	+/-	2.28		34.50	+/-	4.18
1-Methylnaphthalene	4.76	+/-	1.20		15.90	+/-	2.01
2,6+2,7-Dimethylnaphthalene	2.73	+/-	2.75		6.51	+/-	2.79
1,7+1,3+1,6-Dimethylnaphthalene	3.85	+/-	3.65		8.85	+/-	3.72
2,3+1,4+1,5-Dimethylnaphthalene	1.21	+/-	5.18		2.68	+/-	5.13
1,2-Dimethylnaphthalene	0.38	+/-	3.18		0.81	+/-	3.14
1,8-Dimethylnaphthalene	0.00	+/-	2.62		0.00	+/-	2.59
Biphenyl	0.70	+/-	0.63		3.92	+/-	0.75
2-Methylbiphenyl	-10.27	+/-	1.49		-12.65	+/-	1.60
3-Methylbiphenyl	-3.49	+/-	0.69		-3.60	+/-	0.69
4-Methylbiphenyl	-1.26	+/-	0.56		-1.31	+/-	0.55
A-Trimethylnaphthalene	1.12	+/-	0.50		1.42	+/-	0.50
1-Ethyl-2-methylnaphthalene	0.08	+/-	0.48		0.13	+/-	0.48
B-Trimethylnaphthalene	0.64	+/-	0.50		0.83	+/-	0.50
C-Trimethylnaphthalene	0.51	+/-	0.49		0.77	+/-	0.49
2-Ethyl-1-methylnaphthalene	0.00	+/-	0.48		0.01	+/-	0.48
E-Trimethylnaphthalene	0.43	+/-	0.49		0.55	+/-	0.49
F-Trimethylnaphthalene	0.71	+/-	0.49		0.92	+/-	0.49
G-Trimethylnaphthalene	0.21	+/-	0.50		0.27	+/-	0.49
H-Trimethylnaphthalene	-0.13	+/-	0.48		-0.16	+/-	0.48
1,2,8-Trimethylnaphthalene	-0.06	+/-	0.49		-0.07	+/-	0.48
Acenaphthylene	0.06	+/-	3.14		0.69	+/-	3.11
Acenaphthene	0.13	+/-	1.42		0.25	+/-	1.40
Phenanthrene	3.74	+/-	0.83		11.70	+/-	1.47
Fluorene	0.27	+/-	0.57		2.25	+/-	0.62
A-Methylfluorene	0.21	+/-	0.49		0.49	+/-	0.49
1-Methylfluorene	0.25	+/-	0.49		0.72	+/-	0.49
B-Methylfluorene	-2.02	+/-	0.57		-1.90	+/-	0.57
C-Methylfluorene	4.25	+/-	0.80		10.10	+/-	1.48
A-Methylphenanthrene	-0.26	+/-	0.50		0.22	+/-	0.51
2-Methylphenanthrene	0.51	+/-	0.49		1.22	+/-	0.50
B-Methylphenanthrene	-0.32	+/-	0.48		-0.36	+/-	0.48
C-Methylphenanthrene	-0.34	+/-	0.49		-0.15	+/-	0.49
1-Methylphenanthrene	0.05	+/-	0.49		0.37	+/-	0.48
3,6-Dimethylphenanthrene	-0.18	+/-	0.48		-0.08	+/-	0.48
A-Dimethylphenanthrene	-0.01	+/-	0.48		0.11	+/-	0.48
B-Dimethylphenanthrene	-0.30	+/-	0.48		-0.24	+/-	0.48
C-Dimethylphenanthrene	0.06	+/-	0.49		0.13	+/-	0.48
1,7-Dimethylphenanthrene	-0.09	+/-	0.48		0.00	+/-	0.48
D-Dimethylphenanthrene	-0.07	+/-	0.48		-0.01	+/-	0.48
E-Dimethylphenanthrene	-0.66	+/-	0.36		-0.60	+/-	0.35
Anthracene	0.69	+/-	0.49		2.88	+/-	0.65
9-Methylanthracene	-5.68	+/-	1.11		-5.47	+/-	1.10
Fluoranthene	-3.65	+/-	0.78		0.48	+/-	0.82
Pyrene	4.69	+/-	0.74		8.89	+/-	1.09
A-Methylpyrene	-0.19	+/-	0.49		-0.17	+/-	0.48
B-Methylpyrene	-0.34	+/-	0.48		-0.17	+/-	0.48
C-Methylpyrene	0.29	+/-	0.49		0.67	+/-	0.48
D-Methylpyrene	-0.06	+/-	0.48		0.00	+/-	0.48
E-Methylpyrene	0.05	+/-	0.48		0.14	+/-	0.48
F-Methylpyrene	0.02	+/-	0.68		0.18	+/-	0.68
Retene	0.02	+/-	0.96		0.02	+/-	0.95
Benzonaphthothiophene	0.00	+/-	1.40		0.02	+/-	1.40
Benz(a)anthracene	0.10	+/-	0.54		0.15	+/-	0.50
7-Methylbenz[a]anthracene	-0.14	+/-	0.72		-0.15	+/-	0.71
Chrysene	0.04	+/-	0.79		0.14	+/-	0.79
Benzo(b+j+k)fluoranthene	0.03	+/-	0.50		0.13	+/-	0.48
Benzo(e)pyrene	0.03	+/-	1.53		0.05	+/-	1.53
Benzo(a)pyrene	-0.02	+/-	0.55		-0.02	+/-	0.50
7-Methylbenzo[a]pyrene	-0.11	+/-	1.29		-0.11	+/-	1.29
Indeno[1,2,3-cd]pyrene	-0.02	+/-	1.88		-0.01	+/-	1.87
Dibenz(ah+ac)anthracene	-0.02	+/-	1.01		-0.02	+/-	0.97
Benzo(b)chrysene	-0.10	+/-	1.67		-0.10	+/-	1.67
Benzo(ghi)perylene	-0.45	+/-	0.60		-0.41	+/-	0.55
Coronene	0.03	+/-	0.09		0.04	+/-	0.05
Total	21.65				203.08		

5.0 Summary of Results

The findings of this study are as follows:

- Average FTP particulate emissions for CNG and M85 fueled vehicles were 1.40 and 0.70 mg/mi, respectively. These particulate emission values are low and comparable to those of their gasoline counterparts.
- CNG vehicles produced considerably lower NMHC than RFG vehicles, with reductions of 83% for the FTP and 93% for the US06. CO emissions for CNG vehicles were also lower compared with RFG, with reductions of 38% and 85%, respectively, for the FTP and the US06. Reductions in NMHC and CO were even greater when the contribution from the highest-emitting CNG Dodge Caravan was removed from the average. NO_x emissions for CNG vehicles were comparable to those for the gasoline vehicles for the fleet average, and lower than RFG when CNG vehicle #1 was excluded.
- M85 produced 27% lower NO_x and 36% higher CO emissions than RFG over the FTP. OMHCE emissions were 38% higher on M85 compared with RFG. Total hydrocarbons excluding methanol were lower for M85 than RFG, however.
- M85 produced lower emissions than RFG for THC, NMHC, CO, and NO_x over the US06 cycle. The reductions for M85 relative to RFG were 68%, 72%, 33%, and 44%, respectively, for THC, NMHC, CO, and NO_x.
- FTP average mass-emission rates for methanol and formaldehyde were 224 mg/mi and 19 mg/mi, respectively. Methanol emissions were primarily attributable to cold-start emissions. Methanol and formaldehyde emissions were very low for RFG over the FTP and US06, and for M85 over the US06.
- Particulate, NO_x, and CO emissions were significantly higher for the more aggressive US06 cycle than the FTP for all vehicle/fuel combinations, with some vehicles having significant increases in particulate emissions over the US06. Average US06 particulate emissions were 7.76 and 3.62 mg/mi, respectively, for CNG and M85 vehicles, or a factor of more than 5 greater than the FTP values. Increases relative to the FTP of 72% and 103% were observed for CO and NO_x, respectively, for CNG vehicles over the US06. Increases relative to the FTP of 212% and 143% were observed for CO and NO_x, respectively, for M85 vehicles over the US06.
- Most of the particulate mass was below 10 µm in aerodynamic diameter (77%-92%) with 58%-82% of the mass below 2.5 µm, and 42%-77% below 1.0 µm. The fractions of particulate in the smallest size regions are slightly lower than those observed in previous studies, which could indicate a greater contribution of re-entrained particulate. It should also be noted that low particulate emissions made the measurement of particulate size distributions difficult, especially over the FTP cycle.

- Analysis of particulate samples for organic and elemental carbon, trace elements, and ions revealed that elemental and organic carbon were prominent constituents for all three vehicle groups. Other species identified include possible fuel-derived components (SO_4^{2-} , S) and oil/wear-derived components (Mg, P, Ca, Zn, Fe, Si, and Al). Low emissions levels and large sample-to-sample variability made it difficult to differentiate between the species profiles for different vehicle/fuel combinations.
- PAH emissions were highest for the RFG vehicles over the FTP and the US06. Naphthalene, methylnaphthalenes, and dimethylnaphthalenes were the primary PAH constituents for the RFG vehicles. PAH emissions for M85 vehicles were lower than for RFG vehicles over the FTP and considerably lower over the US06. Naphthalene and methylnaphthalenes were the most prominent PAHs for M85 vehicles. PAH emissions for CNG vehicles were lower than for RFG vehicles over the FTP and US06 cycles, and lower than those for M85 vehicles over the FTP. For CNG, most PAH compounds were identified in relatively low concentrations, and naphthalene and methylnaphthalenes were not identified.
- Hopane and sterane emissions were not measured above the detectable levels for any of the vehicle/fuel groups, indicating that no test vehicles were excessive oil burners.

6.0 Conclusions and Recommendations

Overall, particulate emissions from modern technology CNG and M85 vehicles were low, but comparable to those of similar technology gasoline vehicles. These results indicate that the replacement of gasoline vehicles with AFVs will probably not provide a dramatic reduction in particulate emissions in urban areas. Previous studies have shown more dramatic reductions in PM for alternative fuels used in diesel applications, and research in this area should continue (Wang et al., 1993; Unnasch et al, 1993). AFVs also can provide reductions in gaseous emissions compared with gasoline vehicles. This should be considered in developing air quality management plans.

The results of this study indicate that driving conditions can have a important impact on particulate emissions. This applies even for low-emitting gasoline and alternative fuel vehicles, which showed significant increases over the US06 compared with the FTP. It is recommended that additional studies comparing particulate emissions for the FTP and more aggressive cycles be conducted. Such studies should include larger fleets of vehicles and chemical analyses to help identify the source of the particulate.

The results of this study highlight the difficulty of measuring PM emissions from modern technology low emitting gasoline and alternative fuel vehicles. This is particularly true in the case of measuring size distributions and for chemical analyses, but it also applies to mass emissions. In each case, multiple cycles are required to obtain sufficient mass for analysis.

As particulate emissions from modern technology vehicles continue to decrease to near detectable limits, more advanced methodologies for measuring particulate must be investigated. In this regard, more extensive research in the development of real-time particulate measurement techniques, such as a condensation nuclei counter or spectrophone, should be conducted. Further development of such techniques will also be useful in measuring and determining the origin of particulate emissions from higher emitting gasoline and diesel vehicles.

7.0 References

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Appendix A: Fuel Properties

Table A-1. Fuel Properties for RFG

Fuel Parameter	Units	California Phase 2 Gasoline		
		Specs.	Phillips Analyses	Verification Analyses
Octane	-	91 Min.	91.7	
Distillation				
10% Point	Deg. F	130-150	139	150
50% Point	Deg. F	200-210	203	205
90% Point	Deg. F	290-300	300	296
End Point	Deg. F	390 max.	379	378
Sulfur	Ppmw	30-40	32.5	34.5
RVP	Psi	6.7-7.0	6.9	6.74
Olefins	Vol %	4-6	5.8	5.29
Aromatics	Vol %	22-25	24.2	23.44
Multi-Substituted	Vol %	12-14	14	
Alkyl Aromatics				
Benzene	Vol %	0.8-1.0	0.95	0.88
MTBE	Vol %	10.8-11.2	10.92	10.86

Table A-2. Fuel Properties for M85 Blend (w/RFG)

Fuel Parameter	Units	
API Gravity	-	45.4
Sulfur	ppmw	2.5
RVP	Psi	5.2
Olefins	Vol %	0.60
Aromatics	Vol %	2.99
Methanol	Vol %	88.3
Paraffins	Vol %	5.12
Benzene	Vol %	0.11
MTBE	Vol %	1.39

Table A-3. Fuel Properties for CNG (% Mass)

Fuel Species	% of total hydrocarbons (by Mass)
Methane	95.8%
Ethane	2.8%
Propane	0.7%
Butane	0.3%
Pentane	0.2%
2,2-Dimethylpropane	0.0%
2-Methylbutane	0.2%
Propene	0.1%

Note: inert compounds were not measured in this study, but average approximately
1.41% CO₂ and 0.46% N₂ by volume at the Riverside distribution point (Sinclair)

Appendix B: Particulate and Gas-Phase Emissions Summary for FTP and US06

Table B-1. Particulate and Gas-Phase Emissions Summary for FTP

		Bag 1					Bag 2					Bag 3					Weighted				
		THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM	THC	NMHC	CO	NO _x	PM
		g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi	g/mi	g/mi	g/mi	g/mi	mg/mi
CNG #1	FTP #1	1.075	0.095	5.648	1.460	1.30	0.986	0.082	4.226	1.163	1.09	0.754	0.065	5.041	1.390	0.48	0.941	0.08	4.744	1.287	0.96
	FTP #2	1.049	0.101	5.603	1.407		0.951	0.081	4.315	1.120		0.762	0.065	5.171	1.369		0.919	0.081	4.816	1.248	
CNG #2	FTP #1	0.729	0.083	1.392	0.775	3.12	0.271	0.044	0.273	0.357	2.34	0.324	0.034	0.808	0.320	1.47	0.38	0.05	0.651	0.433	2.26
	FTP #2	0.592	0.018	1.418	0.682		0.247	0.054	0.270	0.275		0.311	0.023	0.553	0.297		0.336	0.038	0.585	0.365	
CNG #3	FTP #1	0.487	0.041	1.595	0.222	1.30	0.101	0.126	0.375	0.007	2.09	0.164	0.018	0.751	0.043	1.40	0.198	0.078	0.731	0.061	1.74
	FTP #2	0.339	0.043	1.169	0.156		0.089	0.043	0.343	0.008		0.178	0.000	0.826	0.039		0.165	0.031	0.646	0.047	
CNG #4	FTP #1	0.476	0.010	0.751	0.673	1.04	0.126	0.034	0.013	0.414	1.36	0.21	0.017	0.033	0.424	0.85	0.221	0.024	0.171	0.470	1.16
	FTP #2	0.46	0.037	1.035	0.681		0.118	0.027	0.010	0.374		0.197	0.026	0.061	0.412		0.211	0.029	0.236	0.448	
CNG #5	FTP #1	0.486	0.013	2.159	0.412	1.91	0.071	0.000	0.061	0.104	0.63	0.173	0.000	0.429	0.110	0.55	0.184	0.003	0.595	0.169	0.87
	FTP #2	0.454	0.000	2.206	0.399		0.094	0.013	0.081	0.176		0.18	0.008	0.361	0.114		0.192	0.009	0.597	0.205	
RFG #1	FTP #1	0.875	0.816	5.973	0.865	9.06	0.055	0.032	0.577	0.189	0.44	0.146	0.111	1.864	0.317	0.94	0.25	0.216	2.047	0.364	2.36
	FTP #2		N.A.					N.A.					N.A.					N.A.			
RFG #2	FTP #1	0.861	0.818	7.269	0.799	1.35	0.024	0.013	0.276	0.159	0.16	0.085	0.062	1.297	0.287	0.28	0.214	0.193	1.999	0.326	0.44
	FTP #2	1.184	1.121	8.228	0.729		0.038	0.006	0.274	0.178		0.111	0.094	1.243	0.277		0.295	0.261	2.186	0.320	
RFG #3	FTP #1	1.214	1.151	7.570	0.859	4.21	0.026	0.013	0.395	0.165	0.34	0.12	0.111	1.457	0.196	1.09	0.297	0.275	2.17	0.317	1.35
	FTP #2	1.402	1.348	6.311	0.881		0.047	0.007	0.614	0.140		0.121	0.13	1.612	0.191		0.347	0.318	2.064	0.307	
RFG #4	FTP #1	1.181	1.125	5.555	0.957	2.51	0.069	0.045	0.86	0.224	0.53	0.149	0.121	2.150	0.313	1.32	0.321	0.289	2.184	0.400	1.16
	FTP #2	0.939	0.884	5.350	0.939		0.054	0.030	1.054	0.223		0.145	0.112	2.282	0.377		0.262	0.229	2.277	0.413	
RFG #5	FTP #1	1.126	1.062	7.606	0.979	2.49	0.059	0.036	0.954	0.232	0.55	0.121	0.089	1.910	0.374	0.46	0.297	0.263	2.591	0.425	0.92
	FTP #2	0.931	0.875	6.297	0.911		0.062	0.039	0.973	0.213		0.145	0.112	2.539	0.383		0.265	0.232	2.505	0.404	

Table B-1. Particulate and Gas-Phase Emissions Summary for FTP (concluded)

		Bag 1					Bag 2					Bag 3					Weighted				
		THC g/mi	NMHC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	THC g/mi	NMHC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	THC g/mi	NMHC g/mi	CO g/mi	NO _x g/mi	PM mg/mi	THC g/mi	NMHC g/mi	CO g/mi	NO _x g/mi	PM mg/mi
M85 #1	FTP #1	0.547	0.524	5.997	0.417	0.77	0.028	0.01	1.772	0.178	0.06	0.058	0.043	1.981	0.304	0.26	0.144	0.125	2.704	0.262	0.26
	FTP #2	0.781	0.761	6.746	0.484		0.015	0.002	1.466	0.220		0.042	0.033	2.028	0.330		0.181	0.168	2.714	0.305	
M85 #2	FTP #1	0.515	0.491	6.443	0.332	1.44	0.026	0.015	0.450	0.165	0.70	0.031	0.019	0.957	0.239	0.30	0.129	0.114	1.828	0.220	0.75
	FTP #2	0.467	0.445	4.847	0.360		0.034	0.02	0.506	0.165		0.039	0.027	0.941	0.201		0.125	0.110	1.521	0.215	
M85 #3	FTP #1	0.627	0.598	5.840	0.372	0.53	0.031	0.017	0.778	0.173	0.56	0.045	0.033	1.364	0.190	0.27	0.158	0.141	1.982	0.219	0.47
	FTP #2	0.654	0.63	5.710	0.372		0.028	0.015	0.870	0.161		0.067	0.053	2.516	0.164		0.168	0.152	2.321	0.205	
M85 #4	FTP #1	0.514	0.492	5.294	0.383	2.69	0.013	0.002	0.948	0.181	0.94	0.053	0.039	1.529	0.251	1.01	0.128	0.113	2.007	0.242	1.32
	FTP #2	0.710	0.678	8.441	0.362		0.024	0.009	1.053	0.169		0.045	0.028	1.604	0.255		0.171	0.152	2.731	0.233	
M85 #5	FTP #1	0.879	0.834	9.403	0.153	1.26	0.019	0.015	0.930	0.055	0.5	0.027	0.016	1.712	0.117	0.69	0.199	0.185	2.900	0.092	0.71
	FTP #2	0.848	0.811	9.169	0.148		0.019	0.009	1.290	0.061		0.030	0.019	1.901	0.111		0.194	0.178	3.089	0.093	
RFG #1	FTP #1	0.641	0.606	5.894	0.654	0.55	0.029	0.014	0.906	0.174	0.09	0.090	0.068	1.326	0.493	0.05	0.172	0.151	2.052	0.361	0.17
	FTP #2	0.655	0.617	5.722	0.628		0.015	0.001	0.769	0.147		0.094	0.071	1.328	0.511		0.169	0.148	1.948	0.346	
RFG #2	FTP #1	0.494	0.463	6.185	0.413	1.78	0.008	0.003	0.108	0.112	0.13	0.028	0.016	0.301	0.290	0.03	0.114	0.101	1.416	0.223	0.45
	FTP #2	0.465	0.434	6.554	0.417		0.011	0.005	0.148	0.152		0.040	0.028	0.440	0.308		0.114	0.101	1.566	0.250	
RFG #3	FTP #1	0.518	0.481	5.958	0.512	1.09	0.018	0.007	0.423	0.201	0.33	0.080	0.062	0.995	0.330	0.44	0.138	0.120	1.723	0.301	0.52
	FTP #2	0.510	0.475	5.522	0.553		0.019	0.009	0.478	0.158		0.076	0.057	0.910	0.350		0.136	0.118	1.636	0.292	
RFG #4	FTP #1	0.604	0.574	5.032	0.454	2.53	0.000	0.000	0.788	0.159	2.00	0.068	0.053	0.734	0.371	0.49	0.149	0.138	1.685	0.283	1.69
	FTP #2	0.600	0.566	5.793	0.484		0.018	0.004	0.684	0.166		0.096	0.073	1.081	0.338		0.159	0.139	1.848	0.279	
RFG #5	FTP #1	0.433	0.394	6.141	0.499	0.68	0.015	0.005	0.631	0.136	0.41	0.039	0.023	0.971	0.370	0.32	0.108	0.090	1.863	0.275	0.44
	FTP #2	0.411	0.372	5.820	0.459		0.017	0.007	0.616	0.135		0.051	0.035	0.963	0.336		0.108	0.090	1.789	0.257	

Table B-2. Particulate and Gas-Phase Emissions Summary for US06

Dodge Caravans

		THC	NMHC	CO	NO _x	PM				THC	NMHC	CO	NO _x	PM
		g/mi	g/mi	g/mi	g/mi	mg/mi				g/mi	g/mi	g/mi	g/mi	mg/mi
CNG #1	US06 #1	0.583	0.057	5.809	2.944	12.46		RFG #1	US06 #1	0.300	0.252	15.483	0.761	7.99
	US06 #2	0.580	0.052	7.047	3.011				US06 #2	0.200	0.168	5.302	0.697	
	US06 #3	0.575	0.055	7.018	3.260				US06 #3	0.195	0.151	5.242	0.715	
	US06 #4	0.569	0.056	6.866	3.320				US06 #4	0.250	0.205	10.313	0.674	
CNG #2	US06 #1	0.169	0.000	1.757	0.596	5.24		RFG #2	US06 #1	0.183	0.146	10.82	0.594	1.83
	US06 #2	0.199	0.012	1.727	0.632				US06 #2	0.139	0.113	8.805	0.440	
	US06 #3	0.16	0.013	1.912	0.634				US06 #3	0.135	0.103	7.932	0.462	
	US06 #4	0.163	0.022	1.829	0.627				US06 #4	0.181	0.143	15.483	0.453	
CNG #3	US06 #1	0.109	0.000	1.365	0.281	4.74		RFG #3	US06 #1	0.333	0.277	20.494	0.589	11.63
	US06 #2	0.127	0.006	1.664	0.226				US06 #2	0.255	0.209	14.229	0.536	
CNG #4	US06 #1	0.157	0.012	0.494	0.455	13.77		RFG #4	US06 #1	0.449	0.371	29.526	0.739	7.95
	US06 #2	0.133	0.002	0.352	0.461				US06 #2	0.370	0.307	21.375	0.783	
CNG #5	US06 #1	0.122	0.006	1.381	0.353	2.60		RFG #5	US06 #1	0.283	0.235	15.922	0.872	3.74
	US06 #2	0.122	0.009	1.483	0.316				US06 #2	0.296	0.241	21.637	0.884	

Ford Tauruses

M85 #1	US06 #1	0.018	0.014	2.257	1.053	2.91		RFG #1	US06 #1	0.304	0.276	8.188	1.442	2.62
	US06 #2	0.023	0.020	2.208	1.036				US06 #2	0.275	0.246	9.552	1.204	
	US06 #3	0.018	0.016	2.672	0.85				US06 #3	0.232	0.211	4.885	1.414	
	US06 #4	0.015	0.013	2.441	0.848				US06 #4	0.223	0.198	6.897	1.435	
M85 #2	US06 #1	0.020	0.013	2.237	0.639	3.50		RFG #2	US06 #1	0.073	0.062	3.194	0.922	2.47
	US06 #2	0.036	0.031	1.760	0.541				US06 #2	0.064	0.055	2.491	0.994	
	US06 #3	0.041	0.035	2.364	0.543				US06 #3	0.064	0.055	2.585	1.000	
	US06 #4	0.025	0.018	2.184	0.545				US06 #4	0.076	0.066	2.446	1.035	
M85 #3	US06 #1	0.060	0.046	7.775	0.357	2.96		RFG #3	US06 #1	0.144	0.119	9.969	0.728	3.04
	US06 #2	0.083	0.068	7.727	0.355				US06 #2	0.173	0.141	11.349	0.614	
M85 #4	US06 #1	0.073	0.058	7.311	0.437	1.63		RFG #4	US06 #1	0.126	0.105	8.728	0.842	4.12
	US06 #2	0.026	0.017	3.918	0.495				US06 #2	0.149	0.126	9.141	0.734	
M85 #5	US06 #1	0.103	0.073	22.25	0.182	7.08		RFG #5	US06 #1	0.184	0.137	25.656	0.670	8.32
	US06 #2	0.063	0.041	16.223	0.220				US06 #2	0.180	0.135	25.242	0.673	

**Appendix C: Emissions Summary of Alcohols, Aldehydes, and
Ketones for FTP and US06**

Table C-1. Emissions Summary of Alcohols, Aldehydes, and Ketones for FTP

	RFG Dodge Caravan #1				RFG Dodge Caravan #2				RFG Dodge Caravan #3				RFG Dodge Caravan #4				RFG Dodge Caravan #5			
	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi
Methanol	12.42	0.00	0.00	2.59	6.77	0.00	2.71	2.15	6.50	0.00	0.00	1.35	8.31	0.00	1.22	2.06	4.66	0.00	0.00	0.96
<i>Aldehydes</i>																				
Formaldehyde	12.46	0.00	1.54	3.02	9.50	2.38	0.35	3.32	7.31	2.88	1.65	3.47	2.38	5.27	1.12	3.54	6.74	3.45	1.36	3.63
Acetaldehyde	5.40	0.00	1.06	1.42	4.63	0.85	0.00	1.41	2.85	0.39	1.00	1.07	0.64	0.45	0.86	0.60	5.32	0.66	1.01	1.72
Propionaldehyde	0.26	0.00	0.28	0.13	0.00	0.00	0.00	0.00	0.00	0.21	0.49	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acrolein	4.33	0.00	2.66	1.63	4.31	1.70	0.00	1.78	2.09	0.51	2.35	1.35	0.19	0.33	1.81	0.71	5.60	2.02	0.39	2.32
Methacrolein	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	1.76	0.00	0.00	0.37	0.52	0.00	0.00	0.11	0.00	0.00	0.00	0.00
n-Butyraldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crotonaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	2.61	0.00	0.00	0.54
Pentanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.82	0.00	0.00	0.58
Hexanaldehyde	2.44	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Aromatic Aldehydes</i>																				
Benzaldehyde	0.00	0.00	0.00	0.00	1.81	0.00	0.00	0.38	0.00	0.28	0.00	0.14	0.44	0.00	0.00	0.09	0.00	0.00	0.00	0.00
p-Tolualdehyde	2.98	0.00	0.00	0.62	2.36	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.10	0.00	0.00	0.00	0.00
<i>Ketones</i>																				
Acetone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butanone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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 C-1. Emissions Summary of Alcohols, Aldehydes, and Ketones for FTP (continued)

	RFG Ford Taurus #1				RFG Ford Taurus #2				RFG Ford Taurus #3				RFG Ford Taurus #4				RFG Ford Taurus #5			
	Phase 1	Phase 2	Phase 3	Wghtd	Phase 1	Phase 2	Phase 3	Wghtd	Phase 1	Phase 2	Phase 3	Wghtd	Phase 1	Phase 2	Phase 3	Wghtd	Phase 1	Phase 2	Phase 3	Wghtd
	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi	mg/mi
Methanol	7.35	0.00	0.00	1.52	7.05	0.00	0.00	1.45	5.44	0.00	0.00	1.12	7.38	0.00	0.00	1.52	10.89	0.00	0.00	2.25
<i>Aldehydes</i>																				
Formaldehyde	9.14	2.69	1.26	3.63	7.59	2.01	0.91	2.86	7.80	2.80	0.77	3.28	13.28	6.99	0.95	6.64	5.99	1.80	0.54	2.32
Acetaldehyde	2.94	0.15	1.13	0.99	1.95	0.19	0.81	0.72	2.16	0.17	0.38	0.64	2.95	0.55	0.44	1.02	1.85	0.57	0.32	0.76
Propionaldehyde	0.19	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acrolein	2.88	0.41	2.08	1.38	1.98	0.19	1.21	0.84	2.50	0.74	1.38	1.28	3.14	0.96	1.57	1.58	2.30	1.00	2.31	1.63
Methacrolein	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.33	0.00	0.00	0.28	0.60	0.00	0.17	0.17	0.00	0.00	0.00	0.00
n-Butyraldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crotonaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pentanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hexanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Aromatic Aldehydes</i>																				
Benzaldehyde	1.00	0.00	0.00	0.21	0.46	0.00	0.00	0.10	0.54	0.00	0.00	0.11	0.77	0.00	0.00	0.16	0.50	0.00	0.00	0.10
p-Tolualdehyde	0.45	0.00	0.00	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	0.00	0.00	0.00	0.00
<i>Ketones</i>																				
Acetone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butanone	1.08	0.00	0.00	0.22	0.60	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.00	0.00	0.11

Table C-1. Emissions Summary of Alcohols, Aldehydes, and Ketones for FTP (concluded)

	M85 Ford Taurus #1				M85 Ford Taurus #2				M85 Ford Taurus #3				M85 Ford Taurus #4				M85 Ford Taurus #5			
	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi	Phase 1 mg/mi	Phase 2 mg/mi	Phase 3 mg/mi	Wghtd mg/mi
Methanol	825.68	1.82	51.84	185.55	777.68	0.00	10.67	164.43	1140.05	12.32	19.93	248.08	885.48	2.44	26.06	191.16	1585.86	5.07	10.43	332.81
<i>Aldehydes</i>																				
Formaldehyde	49.71	11.01	2.15	16.62	43.63	9.26	1.84	14.40	55.15	12.41	2.29	18.54	54.64	12.48	2.00	18.32	103.19	13.19	1.52	28.57
Acetaldehyde	3.84	1.17	1.45	1.81	14.63	0.00	1.63	3.49	2.95	0.47	1.32	1.22	1.81	0.95	0.90	1.11	2.10	0.96	0.62	1.10
Propionaldehyde	1.13	0.00	0.00	0.23	2.87	0.00	0.00	0.60	1.44	1.27	0.00	0.96	0.53	0.00	0.00	0.11	0.00	0.00	0.00	0.00
Acrolein	1.63	0.83	4.52	2.01	1.66	0.98	5.83	2.46	1.32	0.49	5.42	2.02	3.14	1.40	4.68	2.65	2.72	2.38	3.62	2.79
Methacrolein	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.10	0.00	0.00	0.44	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
n-Butyraldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crotonaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pentanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hexanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Aromatic Aldehydes</i>																				
Benzaldehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.10
p-Tolualdehyde	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Ketones</i>																				
Acetone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butanone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	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 C-2. Emissions Summary of Alcohols, Aldehydes, and Ketones for US06

	RFG Dodge Caravans		RFG Ford Taurus		M85 Ford Taurus	
	Vehicle #1	Vehicle #2	Vehicle #1	Vehicle #2	Vehicle #1	Vehicle #2
	(mg/mi)	(mg/mi)	(mg/mi)	(mg/mi)	(mg/mi)	(mg/mi)
Methanol	0.00	0.00	4.00	0.00	0.00	3.00
<i>Aldehydes</i>						
Formaldehyde	0.19	1.01	2.07	2.12	6.00	3.37
Acetaldehyde	0.20	0.64	1.00	4.16	0.00	1.86
Propionaldehyde	0.00	0.00	0.00	0.58	5.00	0.00
Acrolein	0.02	0.75	0.10	0.81	0.00	1.10
Methacrolein	0.00	0.00	0.00	0.00	0.00	0.00
n-Butyraldehyde	0.00	0.00	0.00	0.00	0.00	0.00
Crotonaldehyde	0.00	0.00	0.00	0.00	0.00	0.00
Pentanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00
Hexanaldehyde	0.00	0.00	0.00	0.00	0.00	0.00
<i>Aromatic Aldehydes</i>						
Benzaldehyde	0.10	0.44	0.27	0.00	0.00	0.00
p-Tolualdehyde	0.00	0.00	0.14	0.00	0.00	0.00
<i>Ketones</i>						
Acetone	0.00	0.00	0.00	0.00	0.00	0.00
Butanone	0.08	0.00	0.00	0.00	0.00	0.00

Appendix D: Particulate Size Distributions

Table D-1. Particulate Size Distributions (in % of Total Mass)

Vehicle #	CNG Dodge Caravans over FTP			Vehicle #	CNG Dodge Caravans over US06		
	<10 µm	<2.5 µm	<1.0 µm		<10.0 µm	<2.5 µm	<1.0 µm
1	67.9±28.9	41.1±31.1	17.9±22.8	1	88.8±1.4	58.0±1.8	46.8±1.8
2	92.0±18.6	77.0±23.4	64.0±25.2	2	85.1±9.0	62.9±11.4	39.6±12.3
3	71.2±12.9	60.6±16.9	44.2±15.3	3	70.9±10.3	53.8±10.9	24.1±8.2
4	67.4±17.6	52.2±18.7	34.8±15.4	4	90.0±5.3	73.2±5.6	58.8±5.7
5	86.5±23.7	66.2±24.4	48.6±22.8	5	77.0±13.6	62.3±14.5	41.0±12.5
Average	77.0	59.4	41.9	Average	82.4	62.0	42.1
St. Dev.	11.4	13.6	17.1	St. Dev.	8.2	7.2	12.6

	RFG Dodge Caravans over FTP				RFG Dodge Caravans over US06		
1	96.9±5.9	92.6±8.0	87.7±9.3	1	89.5±1.5	63.6±1.9	51.8±2.0
2	85.1±7.5	59.1±9.6	43.0±10.1	2	86.4±7.7	34.3±11.7	18.6±12.1
3	92.6±6.2	83.2±6.9	75.2±8.0	3	95.8±2.2	77.0±2.3	56.7±2.2
4	92.2±11.9	84.4±13.5	77.9±16.0	4	98.6±3.3	79.9±3.4	65.2±3.5
5	84.7±12.0	72.9±13.1	65.3±14.6	5	87.7±4.9	58.7±4.9	32.4±3.9
Average	90.3	78.4	69.8	Average	91.6	62.7	44.9
St. Dev.	5.3	12.9	17.0	St. Dev.	5.3	18.2	19.0

	FFV Ford Tauruses (M85) over FTP				FFV Ford Tauruses (M85) over US06		
1	69.4±22.5	44.4±24.0	33.3±19.4	1	78.1±7.9	65.2±8.5	59.0±9.2
2	81.1±22.8	56.8±23.4	54.1±24.5	2	81.2±5.9	59.7±7.5	50.0±7.9
3	80.5±10.9	74.0±12.4	67.5±14.0	3	93.5±20.2	79.3±21.6	50.0±18.6
4	100.0±34.1	93.1±39.0	72.9±39.6	4	50.0±22.6	50.0±22.6	50.0±22.6
5	36.2±13.9	25.4±13.9	20.3±9.3	5	96.8±7.7	82.0±8.1	66.4±8.5
Average	77.0	58.4	51.6	Average	84.3	68.1	53.0
St. Dev.	23.5	26.2	22.3	St. Dev.	18.5	13.4	7.4

	FFV Ford Tauruses (RFG) over FTP				FFV Ford Tauruses (RFG) over US06		
1	85.0±14.5	61.7±14.7	51.7±14.6	1	91.2±5.3	81.9±5.9	77.2±7.1
2	94.4±13.2	87.3±15.1	78.9±17.5	2	91.1±6.3	82.9±8.3	76.7±9.4
3	81.6±17.3	63.3±18.1	36.7±14.8	3	NA	NA	NA
4	97.0±9.7	79.8±10.1	62.6±10.2	4	92.9±7.3	90.1±8.7	79.4±9.9
5	84.5±6.7	83.7±8.0	76.7±9.4	5	96.6±4.1	85.6±4.5	78.5±5.3
Average	87.0	70.8	55.8	Average	91.2	82.4	77.0
St. Dev.	6.8	11.9	17.7	St. Dev.	2.6	3.7	1.2

Note: The error bars for individual tests account for only the error in the mass measurements of the impaction substrate, and does not include the error in sample volume measurements or replicate vehicle tests. The mass errors were determined using standard techniques for propagation of errors and the mass measurement precision for single MOUDI substrates developed from replicate weighings of test filters.

Appendix E: Comparison of PTFE Filter and MOUDI Mass Emission Rates

Table E-1. Comparison of PTFE Filter and MOUDI Mass Emission Rates

	PTFE mass emission rate mg/mi	MOUDI mass emission rate mg/mi
<i>CNG Dodge Caravans</i>		
FTP #1	0.95	0.89
FTP #2	2.29	1.94
FTP #3	1.57	1.96
FTP #4	1.08	1.61
FTP #5	1.01	1.25
US06 #1	12.46	14.35
US06 #2	5.24	4.01
US06 #3	4.74	4.68
US06 #4	13.77	17.94
US06 #5	2.60	3.23
<i>RFG Dodge Caravans</i>		
FTP #1	3.39	5.21
FTP #2	0.58	1.94
FTP #3	1.83	2.04
FTP #4	1.42	1.12
FTP #5	1.14	0.98
US06 #1	7.99	9.60
US06 #2	1.83	1.82
US06 #3	11.63	12.03
US06 #4	7.95	8.53
US06 #5	3.74	5.06
<i>M85 Ford Tauruses</i>		
FTP #1	0.35	1.12
FTP #2	0.81	1.22
FTP #3	0.52	2.62
FTP #4	1.56	0.88
FTP #5	0.80	2.25
US06 #1	2.91	2.50
US06 #2	3.50	3.95
US06 #3	2.96	2.30
US06 #4	1.63	1.85
US06 #5	7.08	6.20
<i>RFG Ford Tauruses</i>		
FTP #1	0.22	0.66
FTP #2	0.63	0.92
FTP #3	0.61	0.77
FTP #4	1.66	1.42
FTP #5	0.46	1.91
US06 #1	2.62	2.21
US06 #2	2.47	1.95
US06 #3	3.04	N.A.
US06 #4	4.12	3.57
US06 #5	8.32	7.70

Note: FTP emission rates are unweighted or cumulative over entire cycle

Appendix F: Chemical Mass Emission Rates for FTP Tests

Table F-1. Chemical Mass Emission Rates for FTP Tests

Test Type	CNG Caravan #1 FTP	CNG Caravan #2 FTP	CNG Caravan #3 FTP	CNG Caravan #4 FTP	CNG Caravan #5 FTP
FTP Weight PM	0.96 mg/mi	2.26 mg/mi	1.74 mg/mi	1.16 mg/mi	0.87 mg/mi
FTP cumulative PM	0.95 mg/mi	2.29 mg/mi	1.57 mg/mi	1.08 mg/mi	1.01 mg/mi
Organic Carbon	0.0034 +/- 0.0956	0.6870 +/- 0.1304	0.3212 +/- 0.1110	0.2461 +/- 0.1066	0.1306 +/- 0.1042
Elemental Carbon	-0.0001 +/- 0.0324	0.2291 +/- 0.0327	0.1553 +/- 0.0288	0.6768 +/- 0.0704	0.1267 +/- 0.0263
Total Carbon	0.0033 +/- 0.1108	0.9162 +/- 0.1489	0.4766 +/- 0.1263	0.9230 +/- 0.1473	0.2573 +/- 0.1165
NO ₃ ⁻	-0.0044 +/- 0.0142	0.0942 +/- 0.0193	0.0356 +/- 0.0153	0.0231 +/- 0.0146	0.0267 +/- 0.0144
SO ₄ ²⁻	0.0182 +/- 0.0135	0.1483 +/- 0.0216	0.0306 +/- 0.0141	0.0179 +/- 0.0137	0.0144 +/- 0.0135
Cl ⁻	0.0033 +/- 0.0130	0.0021 +/- 0.0140	-0.0033 +/- 0.0134	-0.0036 +/- 0.0132	-0.0059 +/- 0.0132
NH ₄ ⁺	0.0079 +/- 0.0130	0.0493 +/- 0.0148	0.0184 +/- 0.0135	0.0148 +/- 0.0132	0.0110 +/- 0.0132
Na	-0.0063 +/- 0.0247	-0.0009 +/- 0.0285	0.0030 +/- 0.0234	-0.0063 +/- 0.0243	0.0011 +/- 0.0241
Mg	0.0045 +/- 0.0082	0.0217 +/- 0.0088	0.0003 +/- 0.0082	0.0014 +/- 0.0083	0.0038 +/- 0.0082
Al	0.0007 +/- 0.0036	0.0110 +/- 0.0039	0.0113 +/- 0.0039	0.0021 +/- 0.0037	-0.0005 +/- 0.0037
Si	0.0034 +/- 0.0013	0.0294 +/- 0.0031	0.0179 +/- 0.0021	0.0093 +/- 0.0015	0.0020 +/- 0.0012
P	0.0012 +/- 0.0011	0.0060 +/- 0.0014	0.0010 +/- 0.0011	0.0027 +/- 0.0011	-0.0007 +/- 0.0011
S	0.0090 +/- 0.0012	0.0414 +/- 0.0039	0.0067 +/- 0.0011	0.0168 +/- 0.0018	0.0087 +/- 0.0012
Cl	0.0048 +/- 0.0027	0.0105 +/- 0.0030	0.0025 +/- 0.0027	0.0017 +/- 0.0027	0.0018 +/- 0.0027
K	0.0028 +/- 0.0024	0.0042 +/- 0.0022	0.0021 +/- 0.0021	-0.0014 +/- 0.0027	0.0001 +/- 0.0021
Ca	0.0020 +/- 0.0017	0.0131 +/- 0.0021	0.0029 +/- 0.0017	0.0040 +/- 0.0017	0.0012 +/- 0.0016
Ti	0.0005 +/- 0.0129	0.0019 +/- 0.0130	0.0010 +/- 0.0128	0.0005 +/- 0.0125	0.0000 +/- 0.0131
V	0.0002 +/- 0.0064	0.0009 +/- 0.0059	0.0004 +/- 0.0058	0.0002 +/- 0.0057	0.0000 +/- 0.0065
Cr	0.0004 +/- 0.0019	0.0012 +/- 0.0016	0.0029 +/- 0.0016	0.0003 +/- 0.0016	0.0000 +/- 0.0020
Mn	0.0007 +/- 0.0011	0.0009 +/- 0.0009	0.0006 +/- 0.0009	0.0002 +/- 0.0010	0.0000 +/- 0.0011
Fe	0.0441 +/- 0.0040	0.0409 +/- 0.0037	0.0569 +/- 0.0051	0.0274 +/- 0.0025	0.0507 +/- 0.0046
Co	0.0000 +/- 0.0008	0.0002 +/- 0.0010	0.0000 +/- 0.0012	0.0002 +/- 0.0008	0.0000 +/- 0.0011
Ni	-0.0001 +/- 0.0006	0.0006 +/- 0.0006	0.0013 +/- 0.0006	-0.0001 +/- 0.0006	-0.0001 +/- 0.0006
Cu	0.0001 +/- 0.0006	0.0007 +/- 0.0006	0.0004 +/- 0.0006	0.0004 +/- 0.0006	0.0000 +/- 0.0007
Zn	0.0067 +/- 0.0008	0.0111 +/- 0.0011	0.0036 +/- 0.0006	0.0037 +/- 0.0006	0.0018 +/- 0.0005
Ga	-0.0002 +/- 0.0010	0.0001 +/- 0.0011	-0.0002 +/- 0.0010	-0.0001 +/- 0.0010	-0.0002 +/- 0.0010
As	0.0000 +/- 0.0012	0.0000 +/- 0.0012	0.0000 +/- 0.0012	0.0000 +/- 0.0012	0.0000 +/- 0.0012
Se	0.0000 +/- 0.0006	0.0001 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006
Br	-0.0001 +/- 0.0006	0.0001 +/- 0.0006	0.0000 +/- 0.0006	0.0001 +/- 0.0006	-0.0001 +/- 0.0006
Rb	-0.0001 +/- 0.0005	-0.0001 +/- 0.0005	-0.0001 +/- 0.0005	-0.0001 +/- 0.0005	0.0000 +/- 0.0005
Sr	0.0000 +/- 0.0006	0.0002 +/- 0.0006	0.0002 +/- 0.0006	0.0001 +/- 0.0006	0.0000 +/- 0.0006
Y	-0.0001 +/- 0.0007	-0.0001 +/- 0.0007	-0.0001 +/- 0.0007	0.0000 +/- 0.0007	0.0000 +/- 0.0007
Zr	0.0003 +/- 0.0008	0.0002 +/- 0.0008	0.0000 +/- 0.0008	0.0000 +/- 0.0008	0.0001 +/- 0.0008
Mo	0.0000 +/- 0.0015	0.0002 +/- 0.0015	0.0001 +/- 0.0015	0.0001 +/- 0.0015	0.0001 +/- 0.0015
Pd	0.0015 +/- 0.0042	0.0000 +/- 0.0044	0.0018 +/- 0.0043	0.0000 +/- 0.0042	0.0000 +/- 0.0043
Ag	0.0002 +/- 0.0050	-0.0001 +/- 0.0051	-0.0012 +/- 0.0051	-0.0012 +/- 0.0049	-0.0012 +/- 0.0051
Cd	0.0001 +/- 0.0051	-0.0006 +/- 0.0052	0.0001 +/- 0.0052	0.0002 +/- 0.0050	-0.0007 +/- 0.0051
In	-0.0007 +/- 0.0062	-0.0007 +/- 0.0064	-0.0007 +/- 0.0063	0.0010 +/- 0.0061	0.0002 +/- 0.0062
Sn	0.0000 +/- 0.0080	0.0000 +/- 0.0082	0.0000 +/- 0.0081	0.0014 +/- 0.0079	0.0002 +/- 0.0080
Sb	0.0000 +/- 0.0092	0.0005 +/- 0.0095	0.0012 +/- 0.0094	0.0014 +/- 0.0091	0.0001 +/- 0.0093
Ba	-0.0132 +/- 0.0340	-0.0110 +/- 0.0349	-0.0132 +/- 0.0346	-0.0129 +/- 0.0335	-0.0065 +/- 0.0343
La	-0.0133 +/- 0.0452	-0.0133 +/- 0.0466	-0.0133 +/- 0.0459	-0.0133 +/- 0.0446	0.0060 +/- 0.0458
Au	-0.0002 +/- 0.0017	0.0002 +/- 0.0018	-0.0001 +/- 0.0017	0.0000 +/- 0.0016	-0.0002 +/- 0.0017
Hg	-0.0002 +/- 0.0014	-0.0002 +/- 0.0014	-0.0002 +/- 0.0014	-0.0002 +/- 0.0013	-0.0002 +/- 0.0014
Tl	-0.0002 +/- 0.0013	-0.0002 +/- 0.0013	-0.0002 +/- 0.0013	-0.0002 +/- 0.0013	-0.0002 +/- 0.0013
Pb	0.0002 +/- 0.0017	0.0007 +/- 0.0017	0.0006 +/- 0.0017	0.0007 +/- 0.0017	0.0000 +/- 0.0017
U	0.0000 +/- 0.0013	0.0001 +/- 0.0013	0.0001 +/- 0.0013	0.0000 +/- 0.0012	0.0001 +/- 0.0013

Table F-1. Chemical Mass Emission Rates for FTP Tests (continued)

Test Type	RFG Caravan #1		RFG Caravan #2		RFG Caravan #3		RFG Caravan #4		RFG Caravan #5	
FTP Weight PM	FTP		FTP		FTP		FTP		FTP	
FTP cumulative	2.36 mg/mi		0.44 mg/mi		1.35 mg/mi		1.16 mg/mi		0.92 mg/mi	
PM	3.39 mg/mi		0.58 mg/mi		1.83 mg/mi		1.42 mg/mi		1.14 mg/mi	
Organic Carbon	0.7405	+/- 0.1307	-0.1465	+/- 0.0940	0.2978	+/- 0.1019	0.1021	+/- 0.0960	-0.0564	+/- 0.0939
Elemental Carbon	2.5819	+/- 0.2536	0.2865	+/- 0.0359	1.1033	+/- 0.1104	0.5760	+/- 0.0609	0.4512	+/- 0.0497
Total Carbon	3.3239	+/- 0.3435	0.1400	+/- 0.1057	1.4011	+/- 0.1752	0.6781	+/- 0.1263	0.3948	+/- 0.1131
NO ₃ ⁻	0.4612	+/- 0.1150	0.0138	+/- 0.0142	-0.0034	+/- 0.0139	0.0193	+/- 0.0143	-0.0135	+/- 0.0139
SO ₄ ²⁻	0.5380	+/- 0.1143	0.0317	+/- 0.0138	-0.0104	+/- 0.0132	0.0190	+/- 0.0135	0.0027	+/- 0.0133
Cl ⁻	0.1896	+/- 0.1050	-0.0100	+/- 0.0130	-0.0050	+/- 0.0130	-0.0071	+/- 0.0130	-0.0068	+/- 0.0130
NH ₄ ⁺	0.1687	+/- 0.1037	0.0072	+/- 0.0130	0.0043	+/- 0.0129	0.0214	+/- 0.0132	0.0037	+/- 0.0130
Na	-0.0063	+/- 0.3191	0.0016	+/- 0.0234	-0.0063	+/- 0.0249	-0.0063	+/- 0.0247	-0.0063	+/- 0.0232
Mg	0.3882	+/- 0.0540	0.0006	+/- 0.0082	0.0021	+/- 0.0083	0.0061	+/- 0.0082	0.0022	+/- 0.0082
Al	0.1791	+/- 0.0251	0.0002	+/- 0.0036	0.0002	+/- 0.0036	0.0040	+/- 0.0036	0.0045	+/- 0.0036
Si	0.4193	+/- 0.0415	0.0012	+/- 0.0011	0.0115	+/- 0.0016	0.0016	+/- 0.0012	0.0004	+/- 0.0012
P	0.2253	+/- 0.0235	0.0003	+/- 0.0011	0.0062	+/- 0.0013	0.0077	+/- 0.0013	0.0045	+/- 0.0011
S	0.2658	+/- 0.0258	0.0053	+/- 0.0010	0.0121	+/- 0.0014	0.0079	+/- 0.0012	0.0011	+/- 0.0009
Cl	0.1276	+/- 0.0167	0.0001	+/- 0.0029	0.0057	+/- 0.0028	0.0024	+/- 0.0027	0.0024	+/- 0.0027
K	0.0034	+/- 0.0336	-0.0004	+/- 0.0024	-0.0009	+/- 0.0026	-0.0008	+/- 0.0024	-0.0006	+/- 0.0023
Ca	0.0947	+/- 0.0134	0.0008	+/- 0.0016	0.0158	+/- 0.0022	0.0122	+/- 0.0020	0.0067	+/- 0.0017
Ti	0.0103	+/- 0.1039	0.0000	+/- 0.0126	0.0008	+/- 0.0125	0.0000	+/- 0.0129	0.0011	+/- 0.0123
V	0.0073	+/- 0.0409	0.0000	+/- 0.0058	0.0002	+/- 0.0057	0.0000	+/- 0.0064	0.0004	+/- 0.0057
Cr	0.0000	+/- 0.0106	0.0000	+/- 0.0016	0.0004	+/- 0.0016	0.0000	+/- 0.0019	0.0006	+/- 0.0015
Mn	0.0043	+/- 0.0085	-0.0001	+/- 0.0010	0.0003	+/- 0.0010	0.0001	+/- 0.0011	0.0004	+/- 0.0009
Fe	0.4284	+/- 0.0388	0.0190	+/- 0.0018	0.0211	+/- 0.0020	0.0291	+/- 0.0027	0.0376	+/- 0.0034
Co	0.0000	+/- 0.0092	0.0000	+/- 0.0007	0.0000	+/- 0.0007	0.0000	+/- 0.0008	0.0000	+/- 0.0009
Ni	0.0053	+/- 0.0058	-0.0001	+/- 0.0006	0.0000	+/- 0.0006	0.0000	+/- 0.0006	0.0001	+/- 0.0006
Cu	0.0523	+/- 0.0053	0.0000	+/- 0.0007	0.0010	+/- 0.0006	0.0005	+/- 0.0006	0.0007	+/- 0.0006
Zn	0.3759	+/- 0.0339	0.0010	+/- 0.0005	0.0081	+/- 0.0009	0.0118	+/- 0.0012	0.0051	+/- 0.0007
Ga	-0.0002	+/- 0.0087	-0.0002	+/- 0.0010	-0.0002	+/- 0.0010	-0.0002	+/- 0.0010	-0.0001	+/- 0.0010
As	0.0014	+/- 0.0101	0.0000	+/- 0.0012	0.0000	+/- 0.0012	0.0001	+/- 0.0012	0.0000	+/- 0.0011
Se	0.0001	+/- 0.0053	0.0000	+/- 0.0006	0.0000	+/- 0.0006	0.0000	+/- 0.0006	0.0000	+/- 0.0006
Br	0.0013	+/- 0.0048	-0.0001	+/- 0.0006	0.0000	+/- 0.0006	0.0000	+/- 0.0006	-0.0001	+/- 0.0006
Rb	0.0011	+/- 0.0044	-0.0001	+/- 0.0005	-0.0001	+/- 0.0005	0.0000	+/- 0.0005	-0.0001	+/- 0.0005
Sr	0.0000	+/- 0.0048	0.0000	+/- 0.0006	0.0000	+/- 0.0006	0.0000	+/- 0.0006	0.0001	+/- 0.0005
Y	0.0024	+/- 0.0060	0.0000	+/- 0.0007	0.0000	+/- 0.0007	-0.0001	+/- 0.0007	-0.0001	+/- 0.0007
Zr	0.0024	+/- 0.0069	0.0000	+/- 0.0008	0.0000	+/- 0.0008	0.0002	+/- 0.0008	0.0000	+/- 0.0008
Mo	0.0037	+/- 0.0129	0.0000	+/- 0.0015	0.0000	+/- 0.0015	0.0000	+/- 0.0015	0.0000	+/- 0.0015
Pd	0.0000	+/- 0.0349	0.0000	+/- 0.0042	0.0006	+/- 0.0042	0.0013	+/- 0.0042	0.0006	+/- 0.0041
Ag	0.0323	+/- 0.0424	-0.0010	+/- 0.0050	0.0001	+/- 0.0049	-0.0002	+/- 0.0050	0.0002	+/- 0.0049
Cd	0.0025	+/- 0.0430	0.0008	+/- 0.0051	0.0003	+/- 0.0050	-0.0004	+/- 0.0051	-0.0007	+/- 0.0050
In	0.0250	+/- 0.0521	-0.0003	+/- 0.0062	0.0005	+/- 0.0061	-0.0007	+/- 0.0062	-0.0007	+/- 0.0060
Sn	0.0242	+/- 0.0677	0.0005	+/- 0.0079	0.0001	+/- 0.0079	0.0009	+/- 0.0080	0.0000	+/- 0.0078
Sb	0.0445	+/- 0.0773	0.0014	+/- 0.0092	0.0000	+/- 0.0091	0.0000	+/- 0.0092	0.0000	+/- 0.0090
Ba	0.0378	+/- 0.2885	-0.0132	+/- 0.0339	-0.0132	+/- 0.0334	-0.0096	+/- 0.0340	-0.0132	+/- 0.0330
La	0.0377	+/- 0.3802	-0.0133	+/- 0.0452	-0.0129	+/- 0.0445	-0.0011	+/- 0.0452	-0.0126	+/- 0.0439
Au	-0.0002	+/- 0.0204	-0.0002	+/- 0.0016	-0.0002	+/- 0.0017	-0.0002	+/- 0.0017	-0.0001	+/- 0.0016
Hg	-0.0002	+/- 0.0118	-0.0002	+/- 0.0014	-0.0002	+/- 0.0013	-0.0002	+/- 0.0014	-0.0002	+/- 0.0013
Tl	-0.0002	+/- 0.0111	-0.0002	+/- 0.0013	-0.0002	+/- 0.0013	-0.0002	+/- 0.0013	-0.0002	+/- 0.0012
Pb	0.0047	+/- 0.0147	0.0000	+/- 0.0017	0.0002	+/- 0.0017	0.0000	+/- 0.0017	0.0002	+/- 0.0016
U	0.0035	+/- 0.0107	0.0000	+/- 0.0013	0.0000	+/- 0.0012	0.0000	+/- 0.0013	0.0000	+/- 0.0012

Table F-1. Chemical Mass Emission Rates for FTP (continued)

Test Type	M85 Taurus #1	M85 Taurus #2	M85 Taurus #3	M85 Taurus #4	M85 Taurus #5
FTP Weight PM	FTP	FTP	FTP	FTP	FTP
FTP cumulative	0.26 mg/mi	0.75 mg/mi	0.47 mg/mi	1.32 mg/mi	0.71 mg/mi
PM	0.35 mg/mi	0.81 mg/mi	0.52 mg/mi	1.56 mg/mi	0.80 mg/mi
Organic Carbon	0.0536 +/- 0.1062	0.1813 +/- 0.1110	-0.1139 +/- 0.1037	0.0848 +/- 0.1075	-0.0156 +/- 0.1053
Elemental Carbon	0.0678 +/- 0.0238	0.1255 +/- 0.0256	-0.0048 +/- 0.0231	0.0754 +/- 0.0240	0.0045 +/- 0.0231
Total Carbon	0.1214 +/- 0.1147	0.3068 +/- 0.1191	-0.1170 +/- 0.1128	0.1602 +/- 0.1153	-0.0111 +/- 0.1135
NO ₃ ⁻	0.0066 +/- 0.0154	-0.0078 +/- 0.0141	0.0036 +/- 0.0141	0.0175 +/- 0.0144	-0.0088 +/- 0.0141
SO ₄ ²⁻	0.0374 +/- 0.0154	0.0228 +/- 0.0138	0.0175 +/- 0.0137	0.0083 +/- 0.0135	-0.0217 +/- 0.0135
Cl ⁻	-0.0056 +/- 0.0146	-0.0022 +/- 0.0132	0.0025 +/- 0.0133	-0.0073 +/- 0.0132	-0.0048 +/- 0.0132
NH ₄ ⁺	0.0118 +/- 0.0148	0.0120 +/- 0.0136	0.0218 +/- 0.0141	0.0037 +/- 0.0133	-0.0116 +/- 0.0131
Na	0.0104 +/- 0.0209	0.0065 +/- 0.0250	0.0095 +/- 0.0209	0.0104 +/- 0.0207	0.0139 +/- 0.0203
Mg	-0.0049 +/- 0.0108	-0.0022 +/- 0.0101	0.0025 +/- 0.0082	-0.0025 +/- 0.0102	-0.0016 +/- 0.0081
Al	-0.0037 +/- 0.0054	-0.0025 +/- 0.0048	-0.0007 +/- 0.0047	-0.0014 +/- 0.0050	-0.0021 +/- 0.0043
Si	0.0048 +/- 0.0014	-0.0003 +/- 0.0012	0.0019 +/- 0.0013	0.0050 +/- 0.0014	-0.0015 +/- 0.0011
P	0.0066 +/- 0.0013	0.0056 +/- 0.0012	0.0040 +/- 0.0012	0.0074 +/- 0.0013	-0.0005 +/- 0.0010
S	0.0103 +/- 0.0014	0.0110 +/- 0.0014	0.0174 +/- 0.0018	0.0097 +/- 0.0013	-0.0050 +/- 0.0009
Cl	0.0035 +/- 0.0028	0.0115 +/- 0.0029	0.0136 +/- 0.0030	0.0036 +/- 0.0027	0.0008 +/- 0.0030
K	-0.0006 +/- 0.0026	0.0014 +/- 0.0021	0.0005 +/- 0.0021	0.0019 +/- 0.0021	0.0000 +/- 0.0021
Ca	0.0141 +/- 0.0022	0.0187 +/- 0.0024	0.0098 +/- 0.0019	0.0186 +/- 0.0024	0.0024 +/- 0.0016
Ti	0.0018 +/- 0.0138	0.0001 +/- 0.0130	0.0007 +/- 0.0128	0.0019 +/- 0.0127	0.0002 +/- 0.0126
V	0.0000 +/- 0.0070	0.0000 +/- 0.0064	0.0000 +/- 0.0063	0.0003 +/- 0.0058	0.0000 +/- 0.0061
Cr	0.0001 +/- 0.0021	0.0056 +/- 0.0017	0.0000 +/- 0.0019	0.0005 +/- 0.0016	0.0006 +/- 0.0018
Mn	-0.0001 +/- 0.0012	0.0001 +/- 0.0011	0.0034 +/- 0.0010	-0.0001 +/- 0.0010	0.0000 +/- 0.0010
Fe	0.0291 +/- 0.0027	0.0312 +/- 0.0029	0.0346 +/- 0.0032	0.0188 +/- 0.0018	0.0149 +/- 0.0014
Co	0.0004 +/- 0.0009	0.0003 +/- 0.0009	0.0002 +/- 0.0009	0.0003 +/- 0.0007	0.0000 +/- 0.0007
Ni	0.0004 +/- 0.0006	0.0018 +/- 0.0006	0.0000 +/- 0.0006	0.0001 +/- 0.0006	0.0002 +/- 0.0006
Cu	0.0004 +/- 0.0006	0.0015 +/- 0.0006	0.0035 +/- 0.0007	0.0026 +/- 0.0006	0.0019 +/- 0.0006
Zn	0.0055 +/- 0.0007	0.0058 +/- 0.0007	0.0094 +/- 0.0010	0.0098 +/- 0.0010	0.0025 +/- 0.0006
Ga	0.0000 +/- 0.0011	-0.0002 +/- 0.0010	-0.0002 +/- 0.0010	-0.0002 +/- 0.0010	0.0000 +/- 0.0010
As	0.0001 +/- 0.0012	0.0000 +/- 0.0012	0.0001 +/- 0.0012	0.0000 +/- 0.0012	0.0000 +/- 0.0011
Se	0.0001 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0001 +/- 0.0006	0.0001 +/- 0.0006
Br	0.0001 +/- 0.0006	-0.0001 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006
Rb	0.0000 +/- 0.0005	-0.0001 +/- 0.0005	-0.0001 +/- 0.0005	0.0000 +/- 0.0005	-0.0001 +/- 0.0005
Sr	0.0001 +/- 0.0006	0.0002 +/- 0.0006	0.0001 +/- 0.0006	0.0003 +/- 0.0005	0.0001 +/- 0.0005
Y	0.0000 +/- 0.0007	-0.0001 +/- 0.0007	-0.0001 +/- 0.0007	-0.0001 +/- 0.0007	0.0000 +/- 0.0007
Zr	0.0000 +/- 0.0008	0.0003 +/- 0.0008	0.0005 +/- 0.0007	0.0004 +/- 0.0007	0.0002 +/- 0.0008
Mo	0.0005 +/- 0.0016	0.0004 +/- 0.0015	0.0000 +/- 0.0015	0.0000 +/- 0.0015	0.0002 +/- 0.0014
Pd	0.0000 +/- 0.0045	0.0000 +/- 0.0043	0.0003 +/- 0.0042	0.0000 +/- 0.0043	0.0004 +/- 0.0042
Ag	-0.0012 +/- 0.0053	-0.0012 +/- 0.0050	-0.0005 +/- 0.0049	0.0001 +/- 0.0050	-0.0004 +/- 0.0049
Cd	-0.0007 +/- 0.0054	-0.0007 +/- 0.0051	-0.0007 +/- 0.0050	-0.0003 +/- 0.0051	0.0004 +/- 0.0050
In	-0.0007 +/- 0.0066	-0.0007 +/- 0.0063	-0.0007 +/- 0.0061	-0.0007 +/- 0.0062	-0.0007 +/- 0.0060
Sn	0.0018 +/- 0.0084	0.0000 +/- 0.0080	0.0004 +/- 0.0079	0.0011 +/- 0.0080	0.0015 +/- 0.0078
Sb	0.0002 +/- 0.0097	0.0010 +/- 0.0093	0.0005 +/- 0.0091	0.0001 +/- 0.0092	0.0019 +/- 0.0090
Ba	-0.0132 +/- 0.0362	-0.0115 +/- 0.0342	-0.0132 +/- 0.0336	-0.0132 +/- 0.0340	-0.0132 +/- 0.0331
La	-0.0025 +/- 0.0478	-0.0016 +/- 0.0454	-0.0018 +/- 0.0446	-0.0123 +/- 0.0452	-0.0040 +/- 0.0441
Au	-0.0002 +/- 0.0017	-0.0002 +/- 0.0017	-0.0002 +/- 0.0017	-0.0002 +/- 0.0017	0.0002 +/- 0.0016
Hg	-0.0002 +/- 0.0014	-0.0002 +/- 0.0014	-0.0002 +/- 0.0013	-0.0002 +/- 0.0014	-0.0002 +/- 0.0013
Tl	-0.0001 +/- 0.0013	-0.0002 +/- 0.0013	-0.0002 +/- 0.0013	-0.0002 +/- 0.0013	-0.0002 +/- 0.0012
Pb	0.0005 +/- 0.0018	0.0009 +/- 0.0015	0.0004 +/- 0.0017	0.0005 +/- 0.0017	0.0008 +/- 0.0015
U	0.0002 +/- 0.0013	0.0000 +/- 0.0013	0.0000 +/- 0.0012	0.0001 +/- 0.0012	0.0000 +/- 0.0012

Table F-1. Chemical Mass Emission Rates for FTP Tests (concluded)

Test Type	RFG Taurus #1	RFG Taurus #2	RFG Taurus #3	RFG Taurus #4	RFG Taurus #5
FTP Weight PM	FTP	FTP	FTP	FTP	FTP
FTP cumulative	0.17 mg/mi	0.45 mg/mi	0.52 mg/mi	1.69 mg/mi	0.44 mg/mi
PM	0.22 mg/mi	0.63 mg/mi	0.61 mg/mi	1.66 mg/mi	0.46 mg/mi
Organic Carbon	-0.1102 +/- 0.0960	0.0206 +/- 0.0987	-0.1405 +/- 0.0958	0.4974 +/- 0.1226	-0.1213 +/- 0.0961
Elemental Carbon	0.1283 +/- 0.0243	0.3697 +/- 0.0401	0.1326 +/- 0.0245	0.2408 +/- 0.0307	0.1807 +/- 0.0270
Total Carbon	0.0181 +/- 0.1046	0.3895 +/- 0.1139	-0.0079 +/- 0.1044	0.7383 +/- 0.1313	0.0594 +/- 0.1052
NO ₃ ⁻	0.0008 +/- 0.0140	-0.0136 +/- 0.0139	0.0197 +/- 0.0143	0.0063 +/- 0.0140	-0.0067 +/- 0.0139
SO ₄ ²⁻	0.0421 +/- 0.0142	-0.0118 +/- 0.0132	0.0315 +/- 0.0138	-0.0122 +/- 0.0132	-0.0267 +/- 0.0133
Cl ⁻	-0.0081 +/- 0.0130	-0.0096 +/- 0.0130	-0.0047 +/- 0.0130	-0.0045 +/- 0.0130	-0.0084 +/- 0.0130
NH ₄ ⁺	0.0100 +/- 0.0133	-0.0065 +/- 0.0129	0.0238 +/- 0.0141	0.0006 +/- 0.0130	-0.0116 +/- 0.0129
Na	-0.0003 +/- 0.0232	0.0039 +/- 0.0243	0.0003 +/- 0.0228	-0.0051 +/- 0.0260	-0.0063 +/- 0.0234
Mg	0.0008 +/- 0.0082	0.0064 +/- 0.0082	-0.0013 +/- 0.0095	-0.0054 +/- 0.0100	0.0006 +/- 0.0082
Al	0.0001 +/- 0.0036	0.0001 +/- 0.0036	-0.0007 +/- 0.0036	0.0010 +/- 0.0037	0.0019 +/- 0.0036
Si	0.0028 +/- 0.0012	0.0046 +/- 0.0013	0.0020 +/- 0.0012	0.0204 +/- 0.0023	0.0185 +/- 0.0021
P	0.0029 +/- 0.0011	0.0045 +/- 0.0012	0.0010 +/- 0.0011	0.0006 +/- 0.0011	0.0024 +/- 0.0011
S	0.0023 +/- 0.0009	0.0006 +/- 0.0009	0.0095 +/- 0.0012	0.0041 +/- 0.0010	-0.0009 +/- 0.0009
Cl	0.0012 +/- 0.0027	0.0022 +/- 0.0027	0.0087 +/- 0.0028	0.0018 +/- 0.0027	0.0033 +/- 0.0027
K	0.0004 +/- 0.0021	-0.0003 +/- 0.0024	0.0005 +/- 0.0021	0.0034 +/- 0.0022	0.0011 +/- 0.0021
Ca	0.0121 +/- 0.0020	0.0229 +/- 0.0027	0.0081 +/- 0.0018	0.0126 +/- 0.0020	0.0081 +/- 0.0018
Ti	0.0000 +/- 0.0128	0.0000 +/- 0.0128	0.0012 +/- 0.0124	0.0021 +/- 0.0130	0.0017 +/- 0.0125
V	0.0000 +/- 0.0063	0.0000 +/- 0.0063	0.0004 +/- 0.0057	0.0000 +/- 0.0065	0.0001 +/- 0.0057
Cr	0.0000 +/- 0.0019	0.0000 +/- 0.0019	0.0005 +/- 0.0015	0.0000 +/- 0.0020	0.0001 +/- 0.0016
Mn	0.0000 +/- 0.0011	-0.0001 +/- 0.0011	0.0000 +/- 0.0010	-0.0001 +/- 0.0011	-0.0001 +/- 0.0010
Fe	0.0166 +/- 0.0016	0.0042 +/- 0.0006	0.0049 +/- 0.0006	0.0140 +/- 0.0014	0.0091 +/- 0.0009
Co	0.0000 +/- 0.0007	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0001 +/- 0.0007	0.0000 +/- 0.0006
Ni	0.0000 +/- 0.0006	-0.0001 +/- 0.0006	0.0001 +/- 0.0006	-0.0001 +/- 0.0006	0.0000 +/- 0.0006
Cu	0.0000 +/- 0.0006	0.0013 +/- 0.0006	0.0013 +/- 0.0006	0.0044 +/- 0.0007	0.0023 +/- 0.0006
Zn	0.0018 +/- 0.0005	0.0041 +/- 0.0006	0.0025 +/- 0.0006	0.0016 +/- 0.0005	0.0033 +/- 0.0006
Ga	-0.0002 +/- 0.0010	-0.0002 +/- 0.0010	-0.0002 +/- 0.0010	-0.0002 +/- 0.0010	-0.0002 +/- 0.0010
As	0.0001 +/- 0.0012	0.0000 +/- 0.0012	0.0000 +/- 0.0011	0.0000 +/- 0.0012	0.0000 +/- 0.0012
Se	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006
Br	0.0001 +/- 0.0006	-0.0001 +/- 0.0006	0.0001 +/- 0.0006	-0.0001 +/- 0.0006	0.0000 +/- 0.0006
Rb	0.0000 +/- 0.0005	0.0000 +/- 0.0005	-0.0001 +/- 0.0005	-0.0001 +/- 0.0005	0.0000 +/- 0.0005
Sr	0.0002 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0000 +/- 0.0006	0.0001 +/- 0.0006
Y	-0.0001 +/- 0.0007	0.0000 +/- 0.0007	0.0000 +/- 0.0007	-0.0001 +/- 0.0007	0.0000 +/- 0.0007
Zr	0.0000 +/- 0.0008	0.0001 +/- 0.0008	0.0003 +/- 0.0007	0.0006 +/- 0.0007	0.0004 +/- 0.0007
Mo	0.0006 +/- 0.0015	0.0001 +/- 0.0015	0.0001 +/- 0.0015	0.0000 +/- 0.0015	0.0000 +/- 0.0015
Pd	0.0001 +/- 0.0042	0.0010 +/- 0.0042	0.0000 +/- 0.0042	0.0000 +/- 0.0043	0.0000 +/- 0.0042
Ag	-0.0002 +/- 0.0049	0.0000 +/- 0.0049	-0.0012 +/- 0.0049	-0.0003 +/- 0.0050	-0.0012 +/- 0.0049
Cd	0.0004 +/- 0.0050	0.0000 +/- 0.0050	-0.0007 +/- 0.0050	-0.0007 +/- 0.0051	-0.0007 +/- 0.0050
In	-0.0007 +/- 0.0061	-0.0007 +/- 0.0061	-0.0007 +/- 0.0061	-0.0007 +/- 0.0062	-0.0007 +/- 0.0061
Sn	0.0000 +/- 0.0079	0.0009 +/- 0.0079	0.0010 +/- 0.0078	0.0010 +/- 0.0080	0.0000 +/- 0.0079
Sb	0.0000 +/- 0.0091	0.0000 +/- 0.0092	0.0016 +/- 0.0091	0.0011 +/- 0.0093	0.0007 +/- 0.0092
Ba	-0.0004 +/- 0.0336	-0.0046 +/- 0.0337	-0.0132 +/- 0.0333	-0.0132 +/- 0.0343	-0.0132 +/- 0.0336
La	-0.0054 +/- 0.0446	-0.0063 +/- 0.0448	-0.0133 +/- 0.0442	0.0032 +/- 0.0456	-0.0108 +/- 0.0448
Au	-0.0002 +/- 0.0016	-0.0002 +/- 0.0016	-0.0002 +/- 0.0016	-0.0002 +/- 0.0017	-0.0002 +/- 0.0016
Hg	-0.0002 +/- 0.0013	-0.0002 +/- 0.0014	-0.0002 +/- 0.0013	-0.0002 +/- 0.0014	-0.0002 +/- 0.0014
Tl	-0.0002 +/- 0.0013	-0.0002 +/- 0.0013	-0.0002 +/- 0.0012	-0.0002 +/- 0.0013	-0.0001 +/- 0.0013
Pb	0.0001 +/- 0.0017	0.0001 +/- 0.0017	0.0003 +/- 0.0016	0.0000 +/- 0.0017	0.0001 +/- 0.0017
U	0.0000 +/- 0.0012	0.0000 +/- 0.0012	0.0001 +/- 0.0012	0.0002 +/- 0.0013	0.0001 +/- 0.0012

Appendix G: Chemical Mass Emission Rates for US06 Tests

Table G-1. Chemical Mass Emission Rates for US06 Tests

Test Type	CNG Caravan #1			CNG Caravan #2			RFG Caravan #1			RFG Caravan #2		
	US06			US06			US06			US06		
US06 PM	12.46 mg/mi			5.24 mg/mi			7.99 mg/mi			1.83 mg/mi		
Organic Carbon	6.7041	+/-	0.6865	1.7299	+/-	0.2085	1.2955	+/-	0.1684	0.6078	+/-	0.1174
Elemental Carbon	1.6487	+/-	0.1632	0.9894	+/-	0.0997	3.6341	+/-	0.3558	0.3236	+/-	0.0386
Total Carbon	8.3528	+/-	0.8129	2.7194	+/-	0.2890	4.9296	+/-	0.4897	0.9314	+/-	0.1413
NO ₃ ⁻	0.0323	+/-	0.0141	0.0493	+/-	0.0151	-0.0033	+/-	0.0134	0.1428	+/-	0.0376
SO ₄ ²⁻	0.0390	+/-	0.0134	0.0444	+/-	0.0136	0.0397	+/-	0.0134	0.2706	+/-	0.0431
Cl ⁻	-0.0011	+/-	0.0123	-0.0023	+/-	0.0126	0.0139	+/-	0.0127	0.0603	+/-	0.0342
NH ₄ ⁺	0.0697	+/-	0.0142	0.0305	+/-	0.0129	0.0225	+/-	0.0126	0.1337	+/-	0.0358
Na	-0.0063	+/-	0.0267	-0.0063	+/-	0.0300	-0.0063	+/-	0.0425	-0.0063	+/-	0.1039
Mg	0.0389	+/-	0.0092	0.0357	+/-	0.0092	0.0810	+/-	0.0114	0.1421	+/-	0.0205
Al	0.0830	+/-	0.0085	0.0409	+/-	0.0054	0.0050	+/-	0.0038	0.0650	+/-	0.0109
Si	0.4903	+/-	0.0439	0.1800	+/-	0.0162	0.0549	+/-	0.0052	0.2196	+/-	0.0210
P	0.0132	+/-	0.0017	0.0280	+/-	0.0028	0.0748	+/-	0.0069	0.1419	+/-	0.0136
S	0.0740	+/-	0.0067	0.0474	+/-	0.0044	0.0604	+/-	0.0055	0.1863	+/-	0.0172
Cl	0.0273	+/-	0.0037	0.0149	+/-	0.0031	0.0469	+/-	0.0051	0.0546	+/-	0.0070
K	0.0294	+/-	0.0034	0.0095	+/-	0.0023	0.0003	+/-	0.0021	0.0069	+/-	0.0032
Ca	0.0150	+/-	0.0021	0.0257	+/-	0.0028	0.0305	+/-	0.0032	0.1706	+/-	0.0159
Ti	0.0072	+/-	0.0116	0.0017	+/-	0.0121	0.0008	+/-	0.0120	0.0000	+/-	0.0312
V	0.0023	+/-	0.0054	0.0004	+/-	0.0056	0.0004	+/-	0.0056	0.0000	+/-	0.0126
Cr	0.0126	+/-	0.0019	0.0038	+/-	0.0016	0.0020	+/-	0.0016	0.0107	+/-	0.0022
Mn	0.0020	+/-	0.0010	0.0008	+/-	0.0009	0.0009	+/-	0.0009	0.0041	+/-	0.0014
Fe	0.2169	+/-	0.0194	0.0948	+/-	0.0085	0.0725	+/-	0.0065	0.6838	+/-	0.0613
Co	0.0000	+/-	0.0035	0.0000	+/-	0.0017	0.0000	+/-	0.0014	0.0000	+/-	0.0112
Ni	0.0040	+/-	0.0007	0.0029	+/-	0.0006	0.0036	+/-	0.0007	0.0091	+/-	0.0012
Cu	0.0020	+/-	0.0006	0.0018	+/-	0.0006	0.0187	+/-	0.0018	0.0192	+/-	0.0020
Zn	0.0206	+/-	0.0019	0.0434	+/-	0.0039	0.1281	+/-	0.0115	0.1924	+/-	0.0173
Ga	-0.0002	+/-	0.0010	-0.0002	+/-	0.0010	-0.0002	+/-	0.0010	-0.0002	+/-	0.0026
As	0.0000	+/-	0.0011	0.0000	+/-	0.0011	0.0000	+/-	0.0012	0.0000	+/-	0.0035
Se	0.0000	+/-	0.0006	0.0000	+/-	0.0006	0.0000	+/-	0.0006	0.0000	+/-	0.0015
Br	0.0007	+/-	0.0005	0.0008	+/-	0.0005	0.0004	+/-	0.0005	0.0033	+/-	0.0008
Rb	0.0001	+/-	0.0005	0.0001	+/-	0.0005	-0.0001	+/-	0.0005	-0.0001	+/-	0.0013
Sr	0.0001	+/-	0.0005	0.0002	+/-	0.0005	0.0001	+/-	0.0005	0.0001	+/-	0.0014
Y	-0.0001	+/-	0.0007	-0.0001	+/-	0.0007	-0.0001	+/-	0.0007	0.0002	+/-	0.0017
Zr	0.0031	+/-	0.0008	0.0010	+/-	0.0007	0.0001	+/-	0.0008	0.0011	+/-	0.0020
Mo	0.0008	+/-	0.0014	0.0004	+/-	0.0014	0.0008	+/-	0.0014	0.0015	+/-	0.0037
Pd	0.0033	+/-	0.0039	0.0000	+/-	0.0041	0.0005	+/-	0.0040	0.0000	+/-	0.0106
Ag	-0.0012	+/-	0.0046	-0.0012	+/-	0.0048	-0.0009	+/-	0.0047	0.0024	+/-	0.0123
Cd	-0.0006	+/-	0.0047	-0.0007	+/-	0.0049	0.0001	+/-	0.0048	0.0004	+/-	0.0126
In	-0.0007	+/-	0.0058	-0.0007	+/-	0.0059	-0.0007	+/-	0.0058	0.0019	+/-	0.0150
Sn	0.0005	+/-	0.0074	0.0008	+/-	0.0076	0.0006	+/-	0.0076	0.0105	+/-	0.0195
Sb	0.0005	+/-	0.0086	0.0014	+/-	0.0088	0.0024	+/-	0.0087	0.0056	+/-	0.0216
Ba	-0.0082	+/-	0.0316	-0.0074	+/-	0.0323	-0.0132	+/-	0.0321	0.0422	+/-	0.0845
La	-0.0133	+/-	0.0421	-0.0133	+/-	0.0431	-0.0133	+/-	0.0427	-0.0133	+/-	0.1093
Au	0.0000	+/-	0.0018	-0.0001	+/-	0.0024	-0.0002	+/-	0.0049	0.0006	+/-	0.0086
Hg	-0.0002	+/-	0.0013	-0.0002	+/-	0.0013	-0.0002	+/-	0.0014	-0.0002	+/-	0.0035
Tl	-0.0002	+/-	0.0012	-0.0002	+/-	0.0012	-0.0002	+/-	0.0012	-0.0002	+/-	0.0031
Pb	0.0006	+/-	0.0015	0.0007	+/-	0.0015	0.0018	+/-	0.0015	0.0105	+/-	0.0023
U	0.0001	+/-	0.0012	0.0000	+/-	0.0012	0.0000	+/-	0.0012	0.0000	+/-	0.0030

Table G-1. Chemical Mass Emission Rates for US06 Tests (concluded)

Test Type	M85 Taurus #1			M85 Taurus #2			RFG Taurus #1			RFG Taurus #2		
US06 PM	US06			US06			US06			US06		
	2.91 mg/mi			3.50 mg/mi			2.62 mg/mi			2.47 mg/mi		
Organic Carbon	0.3944	+/-	0.1187	0.3650	+/-	0.1169	0.3250	+/-	0.1115	0.1781	+/-	0.1039
Elemental Carbon	0.2428	+/-	0.0313	0.6442	+/-	0.0631	0.4760	+/-	0.0486	1.0348	+/-	0.0969
Total Carbon	0.6371	+/-	0.1289	1.0093	+/-	0.1519	0.8009	+/-	0.1349	1.2129	+/-	0.1634
NO ₃ ⁻	-0.0054	+/-	0.0136	-0.0107	+/-	0.0136	-0.0111	+/-	0.0138	-0.0191	+/-	0.0134
SO ₄ ²⁻	0.0029	+/-	0.0130	0.0802	+/-	0.0157	0.0158	+/-	0.0134	-0.0089	+/-	0.0126
Cl ⁻	0.1482	+/-	0.0232	0.0223	+/-	0.0133	-0.0068	+/-	0.0129	-0.0105	+/-	0.0124
NH ₄ ⁺	0.0847	+/-	0.0206	0.0781	+/-	0.0197	0.0158	+/-	0.0135	0.0016	+/-	0.0124
Na	-0.0063	+/-	0.0286	-0.0025	+/-	0.0283	-0.0063	+/-	0.0263	-0.0063	+/-	0.0234
Mg	-0.0048	+/-	0.0116	0.0080	+/-	0.0085	0.0016	+/-	0.0113	0.0000	+/-	0.0082
Al	-0.0017	+/-	0.0061	-0.0037	+/-	0.0064	-0.0037	+/-	0.0062	-0.0013	+/-	0.0047
Si	0.4195	+/-	0.0376	0.5812	+/-	0.0521	0.4925	+/-	0.0442	0.2368	+/-	0.0213
P	0.0089	+/-	0.0015	0.0121	+/-	0.0017	0.0026	+/-	0.0011	0.0064	+/-	0.0012
S	0.0095	+/-	0.0013	0.0680	+/-	0.0062	0.0122	+/-	0.0014	0.0089	+/-	0.0012
Cl	0.2114	+/-	0.0192	0.0657	+/-	0.0066	0.0046	+/-	0.0027	0.0052	+/-	0.0027
K	0.0007	+/-	0.0021	-0.0007	+/-	0.0023	-0.0011	+/-	0.0025	-0.0007	+/-	0.0022
Ca	0.0239	+/-	0.0027	0.0339	+/-	0.0035	0.0148	+/-	0.0021	0.0248	+/-	0.0028
Ti	0.0000	+/-	0.0126	0.0000	+/-	0.0122	0.0000	+/-	0.0125	0.0012	+/-	0.0120
V	0.0000	+/-	0.0061	0.0000	+/-	0.0059	0.0000	+/-	0.0061	0.0000	+/-	0.0058
Cr	0.0000	+/-	0.0018	0.0002	+/-	0.0017	0.0000	+/-	0.0018	0.0002	+/-	0.0017
Mn	0.0000	+/-	0.0010	-0.0001	+/-	0.0010	-0.0001	+/-	0.0010	-0.0001	+/-	0.0010
Fe	0.0463	+/-	0.0042	0.0116	+/-	0.0011	0.0313	+/-	0.0029	0.0055	+/-	0.0007
Co	0.0001	+/-	0.0010	0.0001	+/-	0.0006	0.0000	+/-	0.0008	0.0000	+/-	0.0006
Ni	0.0001	+/-	0.0006	0.0004	+/-	0.0006	0.0000	+/-	0.0006	0.0001	+/-	0.0006
Cu	0.0003	+/-	0.0006	0.0039	+/-	0.0007	0.0003	+/-	0.0006	0.0018	+/-	0.0006
Zn	0.0125	+/-	0.0012	0.0170	+/-	0.0016	0.0040	+/-	0.0006	0.0089	+/-	0.0009
Ga	-0.0002	+/-	0.0010	-0.0001	+/-	0.0010	-0.0002	+/-	0.0010	-0.0002	+/-	0.0010
As	0.0000	+/-	0.0011	0.0000	+/-	0.0011	0.0000	+/-	0.0011	0.0000	+/-	0.0011
Se	0.0000	+/-	0.0006	0.0000	+/-	0.0006	0.0000	+/-	0.0006	0.0000	+/-	0.0006
Br	0.0016	+/-	0.0006	0.0010	+/-	0.0005	0.0003	+/-	0.0005	0.0001	+/-	0.0005
Rb	-0.0001	+/-	0.0005	-0.0001	+/-	0.0005	0.0000	+/-	0.0005	-0.0001	+/-	0.0005
Sr	0.0003	+/-	0.0005	0.0001	+/-	0.0005	0.0003	+/-	0.0005	0.0001	+/-	0.0005
Y	-0.0001	+/-	0.0007	-0.0001	+/-	0.0007	0.0000	+/-	0.0007	-0.0001	+/-	0.0007
Zr	0.0000	+/-	0.0008	0.0005	+/-	0.0007	0.0000	+/-	0.0008	0.0003	+/-	0.0007
Mo	0.0000	+/-	0.0015	0.0001	+/-	0.0014	0.0000	+/-	0.0014	0.0001	+/-	0.0014
Pd	0.0000	+/-	0.0041	0.0001	+/-	0.0041	0.0000	+/-	0.0041	0.0000	+/-	0.0040
Ag	-0.0007	+/-	0.0048	-0.0008	+/-	0.0047	-0.0011	+/-	0.0048	-0.0011	+/-	0.0047
Cd	-0.0007	+/-	0.0049	0.0002	+/-	0.0048	0.0001	+/-	0.0049	-0.0007	+/-	0.0048
In	-0.0007	+/-	0.0060	-0.0007	+/-	0.0059	0.0003	+/-	0.0060	-0.0007	+/-	0.0058
Sn	0.0029	+/-	0.0073	0.0011	+/-	0.0076	0.0010	+/-	0.0077	0.0000	+/-	0.0075
Sb	0.0010	+/-	0.0089	0.0016	+/-	0.0088	0.0000	+/-	0.0089	0.0008	+/-	0.0087
Ba	0.0056	+/-	0.0309	-0.0073	+/-	0.0322	0.0013	+/-	0.0309	-0.0132	+/-	0.0319
La	-0.0034	+/-	0.0435	-0.0023	+/-	0.0427	0.0004	+/-	0.0435	-0.0080	+/-	0.0424
Au	-0.0002	+/-	0.0017	-0.0002	+/-	0.0017	-0.0002	+/-	0.0016	-0.0002	+/-	0.0016
Hg	-0.0002	+/-	0.0013	-0.0001	+/-	0.0013	-0.0001	+/-	0.0013	-0.0002	+/-	0.0013
Tl	-0.0002	+/-	0.0012	-0.0002	+/-	0.0012	-0.0002	+/-	0.0012	-0.0002	+/-	0.0012
Pb	0.0004	+/-	0.0016	0.0012	+/-	0.0015	0.0003	+/-	0.0016	0.0001	+/-	0.0016
U	0.0000	+/-	0.0012	0.0000	+/-	0.0012	0.0000	+/-	0.0012	0.0000	+/-	0.0012

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13. ABSTRACT (<i>Maximum 200 words</i>) The objective of this project was to measure and characterize particulate emissions from light-duty alternative fuel vehicles (AFVs) and equivalent gasoline-fueled vehicles. The project included emission testing of a fleet of 129 gasoline-fueled vehicles and 19 diesel vehicles. Particulate measurements were obtained over Federal Test Procedure and US06 cycles. Chemical characterization of the exhaust particulate was also performed. Overall, the particulate emissions from modern technology compressed natural gas and methanol vehicles were low, but were still comparable to those of similar technology gasoline vehicles.				
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