Exhaust Emission Impacts of Replacing Heavy Aromatic Hydrocarbons in Gasoline with Alternate Octane Sources

United States
Environmental Protection
Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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Executive Summary

High-boiling aromatics have been shown to be the primary contributor to particulate matter (PM) emissions from gasoline engines. The U.S. Environmental Protection Agency (EPA), in collaboration with the Environment and Climate Change Canada (ECCC) and seven global automotive vehicle manufacturers, conducted a gasoline vehicle emissions test program to quantify the emissions impact of replacing a portion of high-boiling aromatics with lower-boiling aromatics, ethanol, and high-octane aliphatic blending components.

The test program included ten high-sales U.S & Canadian light-duty spark-ignited (SI) test vehicles, tested at nine emission labs, using standardized vehicle emissions tests (US EPA FTP and US06), over a set of five specialty-blended test gasolines.

The results indicate the potential for significant tailpipe PM reductions from light duty gasoline vehicles when high-boiling aromatics are replaced with other high-octane blending components. As summarized in Figure ES.1 and Figure ES.2, switching to fuels in which high-boiling aromatics were reduced from 7.4 %v to 4.2-4.5 %v yielded an average PM emission reduction percentage of 35-45% on the FTP Composite cycle and 20-25% on the US06 cycle in this study.

The program also measured regulated gaseous emissions, which are of interest when considering broader air quality impacts of fuel formulation changes. No increase in emissions of NOx, NMOG, nor CO_2 was observed for the test fleet when replacing a portion of heavy aromatics with alternate octane sources.

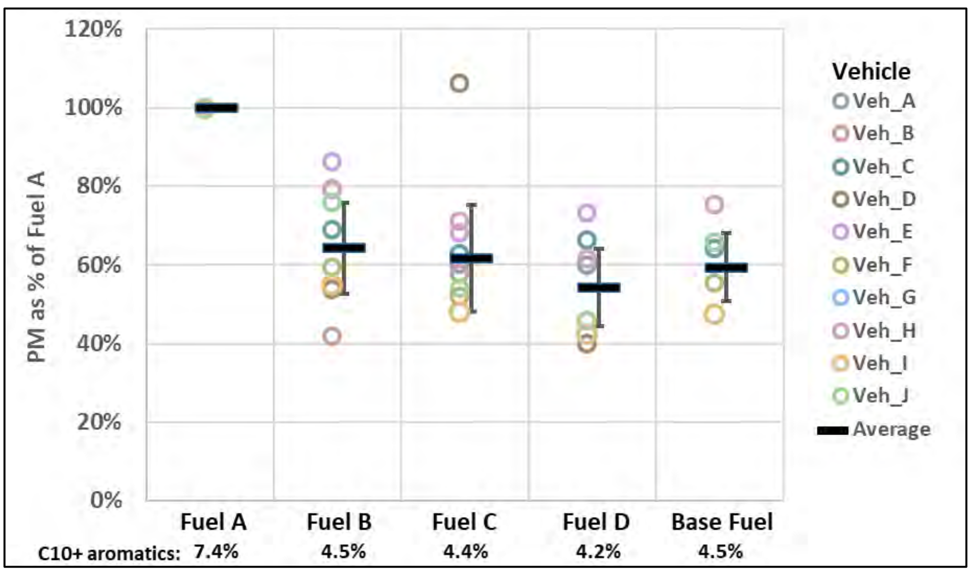

Figure ES.1. Summary of PM emissions reductions for the FTP cycle for each test fuel (relative to Fuel A), shown by vehicle and for the test fleet average with 95% confidence intervals.

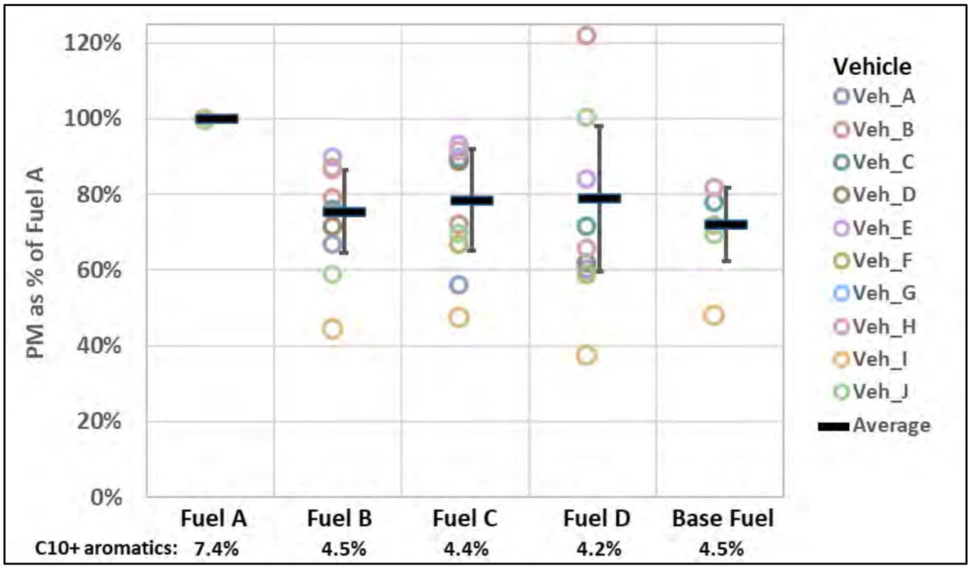

Figure ES.2. Summary of PM emissions reductions for the US06 cycle for each test fuel (relative to Fuel A), shown by vehicle and for the test fleet average with 95% confidence intervals.

1. Introduction

1.1 Background

Particulate matter (PM) pollution has been linked to a multitude of health problems [1, 2]. Particles smaller than 2.5 micrometers in diameter, referred to as PM2.5, pose the greatest risk because they can penetrate deep into the lungs and enter the bloodstream. Exposure to PM2.5 increases the risk of premature death and can impair lung growth in children. For individuals with preexisting health challenges, PM2.5 can increase the risk of cardiovascular and respiratory disease. The United States Environmental Protection Agency (US EPA)'s 2017 National Emissions Inventory estimates that gasoline-fueled vehicles and nonroad equipment contribute 31.9% of the total mobile source primary PM2.5 emissions [1].

Multiple studies have shown that gasoline properties have a major influence on combustion-related PM emissions [3, 4, 5, 6, 7]. Heavy aromatic compounds in particular are major PM contributors. The heavy end of gasoline consists almost exclusively of aromatics, and the heaviest several percent of those species have a disproportionally large impact on the amount of PM emitted.

Advancements continue in engine, aftertreatment, and propulsion technology to mitigate PM emissions. However, these improvements only affect new model year vehicles and engines. Over 250 million gasoline-powered on-road vehicles and about 150 million nonroad vehicles and pieces of equipment exist in the United States [8, 9], with many of them remaining in use for decades. Changes in fuel composition can affect this entire population of equipment, resulting in immediate and substantial PM emission reductions.

1.2 Correlating Fuel Properties with PM Emissions

The PM Index is currently the parameter most frequently used to characterize the propensity of gasoline to generate PM emissions. It was proposed in 2010 by Aikawa and colleagues [3] and has proven to be a robust predictor. It is being widely used in the modeling of fuel impacts on PM emissions from spark-ignited (SI) engine equipped vehicles and has been shown to be directly proportional to PM emissions [4, 6]. The PM Index requires the use of a detailed hydrocarbon analysis (DHA) of the fuel and is calculated using the following equation:

$$\text{PM Index} = \sum_{i=1}^{n}\left[\frac{(DBE_i + 1)}{VP(443K)_i} \times Wt_i\right]$$

where DBE_i is the double bond equivalent of compound i, $VP(443K)_i$ is the vapor pressure of compound i at 443 K, and Wt_i is the weight percent of compound i in the fuel.

DBE_i is related to the degree of chemical-bond unsaturation of each hydrocarbon compound, and therefore to its sooting tendency while the VP term is related to the volatility of each compound. In this way the chemical and physical attributes, respectively, of each compound are considered. Heavy aromatic compounds, such as two aromatic ring naphthalenes, are highly unsaturated and have low vapor pressures. Considering the equation above, it is clear why such fuel components are main contributors to the PM Index (PMI) values of commercial gasolines.

Given that the final PMI value represents the summation of individual fuel component contributions, a detailed hydrocarbon analysis (DHA) is required. DHA is a laboratory method that uses gas chromatography (GC) to separate and quantify each molecular component of a fuel. In practice, it is not possible to identify and quantify 100% of the species in a fuel sample; a typical market gasoline can consist of hundreds of components. However, a recent DHA enhancement [10] has reduced the number of unidentified components to a fraction of a percent, thereby improving the accuracy of the PM Index determination. To achieve this level of quality, analysis times typically run up to three hours, after which the output data must be reviewed by a skilled operator or chemist to confirm that species identifications and quantifications were performed correctly by the software. Post-run corrections may be required in the high-boiling tail region of the chromatogram, a region that has great leverage over the final PMI. The DHA – PMI methodology, while intensive, is a strong predictor of a gasoline's propensity to create vehicle particulate emissions.

1.3 U.S. Gasoline Market Fuel Composition

The aforementioned leverage of heavy aromatic components on the final PMI value can be visualized using data from a recent PMI fuel survey of U.S. market fuels. As detailed in the next section of this paper, this survey was conducted in the summer of 2018 and 2019 by the Alliance for Automotive Innovation. The data shown in are Figure 1.1 are derived from Tables 3.2 – 3.5 in Section 3. Although a single sample was used for this example, the relationships shown are generally sample independent; the values will differ somewhat based upon the concentrations of the specific species within the compound classes and carbon number groups.

Figure 1.1 demonstrates the disparity of PMI influence among aromatic species. Even a tiny volume of heavy aromatics can swing the PMI to a high value. Also, the PMI contribution of all other compound classes is minimal compared to that of the heavy aromatics.

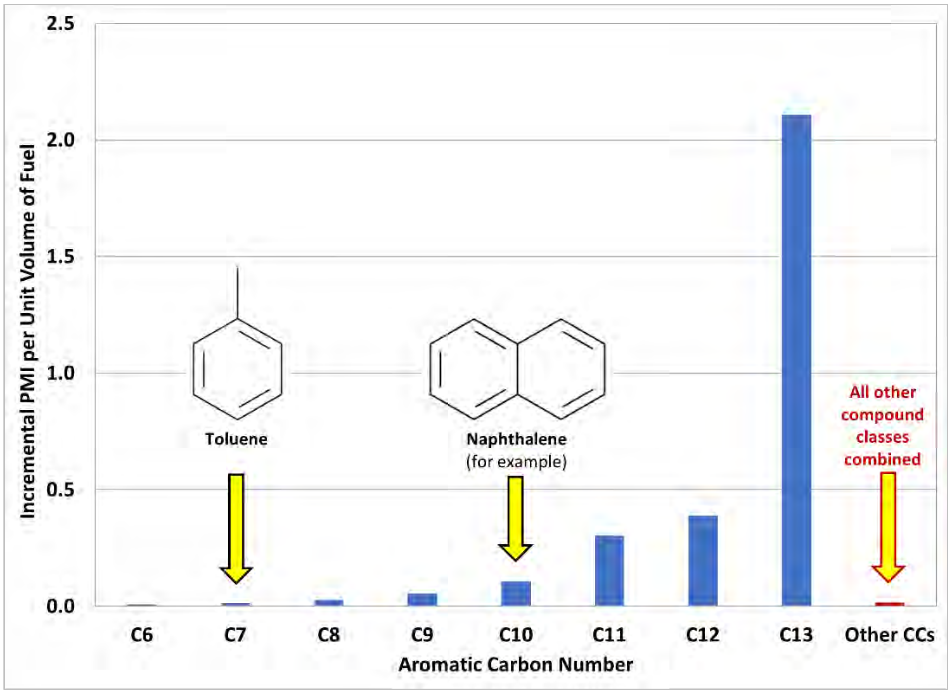

Figure 1.1. Incremental PMI value per unit volume of fuel, listed by carbon number.

To get a complete picture of this heavy aromatic leverage, an understanding of the volume of these species in market gasoline is necessary. The volume information in Figure 1.2 was derived from DHA data from 708 summer regular-grade E10 gasoline samples [11]. To characterize the distribution of aromatic species in U.S. market gasoline, these data were grouped into three categories: total aromatics, monocyclic aromatics (e.g., benzene, toluene, xylenes), and bicyclic aromatics such as naphthalenes and indenes. Their percent content in the tail end of the fuels is presented as a function of the cut-off temperature. (The term "cut-off temperature" is used here to signify that each aromatic datapoint represents species boiling at or above this specific temperature.) Also included in Figure 1.2 is a plot showing the volume fraction of all identified species in the 708 fuels and boiling at or above the cut-off temperature as determined by the ASTM D86 atmospheric distillation test method. It should be noted that the U.S. market generally follows the ASTM D4814 gasoline specification, in which the maximum FBP (final boiling point) is 437°F. Globally, most regions follow the EN228 specification, in which the maximum FBP is 410°F.

It can be seen in this figure that aromatic species dominate the heavy end of U.S. market gasolines, exceeding 90%v at a cut-off temperature of 380°F. Bicyclic aromatics, which are most prone to the generation of PM emissions, dominate its heaviest, least volatile fractions. This correlates with aromatic species ≥C10 in Figure 1.1. As an example, bicyclic aromatics constitute the majority of total aromatics starting just above 400°F, when the fuel fraction above the cut-off falls below 2 v%.

Given that the heaviest few percent of gasoline aromatics are responsible for such a disproportionate effect on PM emissions, it would seem natural to conclude that a distillation adjustment or product shift during the refining process could address this issue. However, these heavy fractions can have high octane ratings; removing even small fractions of these components could cause a drop in the anti-knock index. Also, the volume of gasoline produced would be reduced in proportion to the volume of heavy fractions removed.

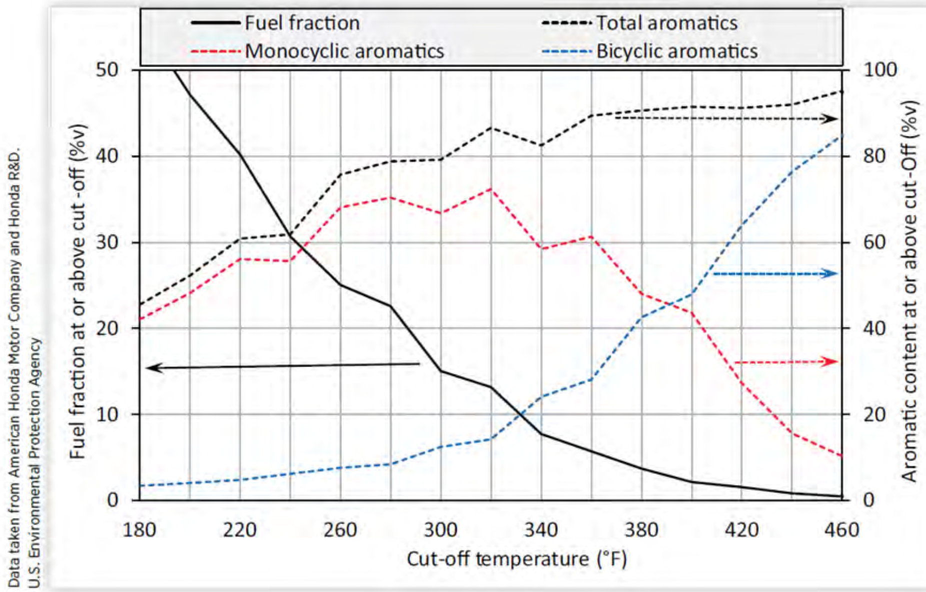

Figure 1.2. The content of aromatic species in the tail ends of US summer E10 regular-grade market gasoline. [11]

1.4 A New Vehicle Emissions Research Program

The loss of octane and volume by removal of a few percent of the heaviest aromatic gasoline blending components described in the previous section could be compensated for by using appropriate lighter, high-octane refinery blending components and/or ethanol. In an effort to verify this concept experimentally, a research program was conducted by seven auto manufacturers, the U.S. EPA, and Environment and Climate Change Canada (ECCC). The program was designed to confirm the assumption listed in Table 1.1.

Table 1.1 Objectives of the gasoline heavy aromatics program.

Assumption	Program Activity to Confirm
• Vehicle PM emissions decrease when the heavy tail of the fuel is replaced with lower-PMI components, under conditions in which octane and volume remain generally constant.	• Conduct a large test program: o 10 vehicles o 9 test facilities (1 → 2 vehicles/lab) o 5 fuels o 2 standardized driving cycles • Fuels: o Base (includes 10%v ethanol) o Base + 3.1%v heavy aromatics o Base + 3.1%v light aromatics o Base + 3.1%v alkylate o Base with 6%v ethanol

2. Vehicle Emissions Study

2.1. Test Fuels

In this study, the Test Fuel Matrix (Table 2.1) consisted of five carefully blended test fuel formulations, developed to mimic a range of U.S. gasoline PMI values and processing changes a petroleum refiner could potentially use to produce lower emission market fuels, while still meeting other market fuel quality limits.

Table 2.1. Test fuel matrix design targets.

Parameter	Base Fuel Typical US Gasoline	Fuel A Base Fuel + 3.1 vol% of C11+ Aromatics	Fuel B Base Fuel + 3.1 vol% of C7-C9 Aromatics	Fuel C Base Fuel + 3.1vol% Alkylate	Fuel D Base Fuel + 6 vol% Ethanol
PM Index Targets	1.6 ± 0.1	2.7 ± 0.1	Report	Report	Report
Ethanol Targets	9 – 10 vol%	9 – 10 vol%	9 – 10 vol%	9 – 10 vol%	14 – 15 vol%
Note: Resultant PMI values of Fuels B,C,D need to be determined by analysis. Aromatic hydrocarbons are listed by their carbon number.					

Fuel A represents a high-PMI, high-distillation-endpoint gasoline in the current U.S. market. It's used as a reference for emissions comparisons with Fuels B, C and D. Fuels B, C, and D represent three possible scenarios for replacement of approximately half of the heavy (>C10 or $C11^+$) aromatic fraction of Fuel A (3%v replaced) with other high-octane hydrocarbons or ethanol, which restores the original octane rating. Fuel B represents a replacement with 3%v of light (≤C10) aromatics while Fuel C represents a replacement with 3%v of alkylate. Fuel D is used to investigate increased ethanol content as a third alternative. Fuels A, B and C contain 9-10% ethanol, reflective of the vast majority of US market gasoline (E10). Fuel D uses an additional 6%v ethanol as replacement for the $C11^+$ aromatics. Blending up to E15 was more ethanol than required for the octane replacement, but reflects a product already being introduced many US markets.

2.1.1. Primary Design Variables

The Particulate Matter Index (PMI), for the reasons described in Section 1.2, was the primary test fuel design parameter used so that the vehicle emissions test fuels would mimic U.S. gasoline and the properties the project participants wanted to study.

To define the Test Fuel Matrix base fuel, program participants analyzed the latest market data from the "Auto Innovators" fuel survey where a large number of samples were hydrocarbon speciated and PMI values derived. The 2018 and 2019 summer season Auto Innovator's PMI fuel survey consisted of 231 gasoline samples. Additional fuel property data were included with the PMI values including octane rating, total aromatics, density, distillation points, etc. Figure 2.1 and Figure 2.2 summarize the range of PMI values for the 2018 and 2019 samples. For 2018 & 2019 combined, the market fuels show a median PMI of 1.5-1.6 for regular and premium grades with a maximum PMI value of 2.8. Figure 2.3 shows the aromatics range by volume percent by carbon numbers and PMI ranges.

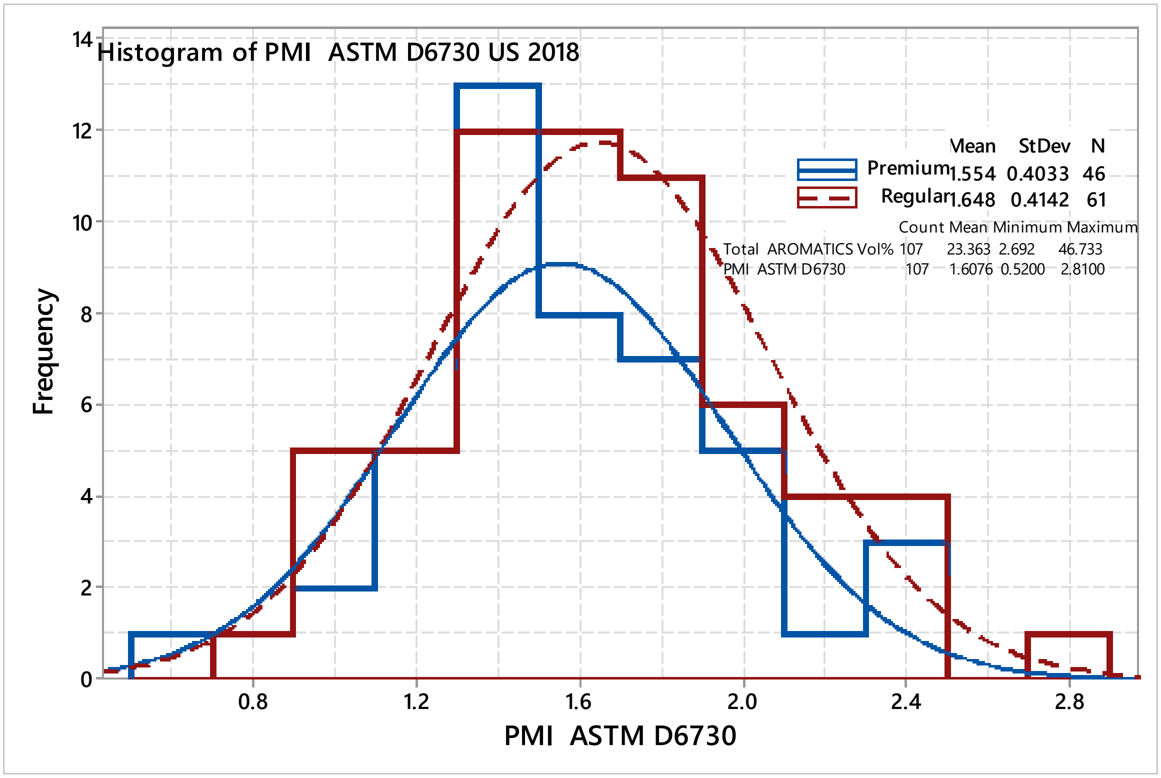

Figure 2.1. Histogram of PMI of US 2018 gasoline per ASTM D6730.

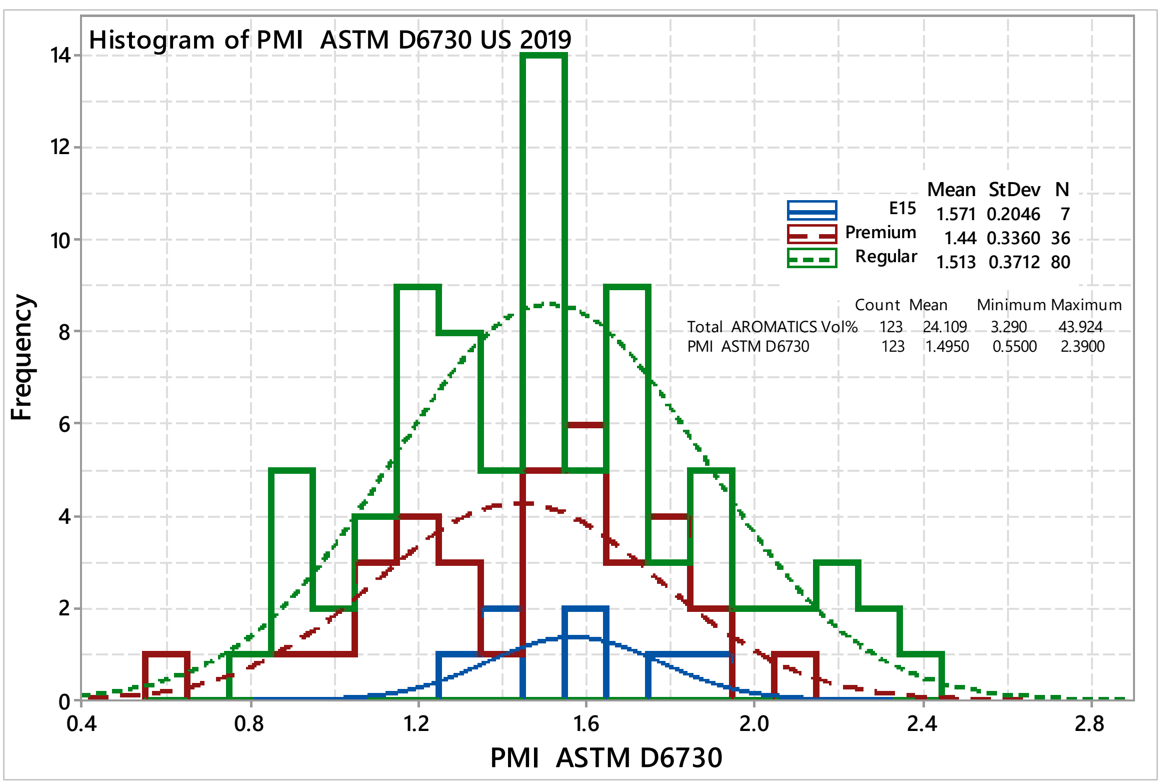

Figure 2.2. Histogram of PMI of US 2019 gasoline per ASTM D6730.

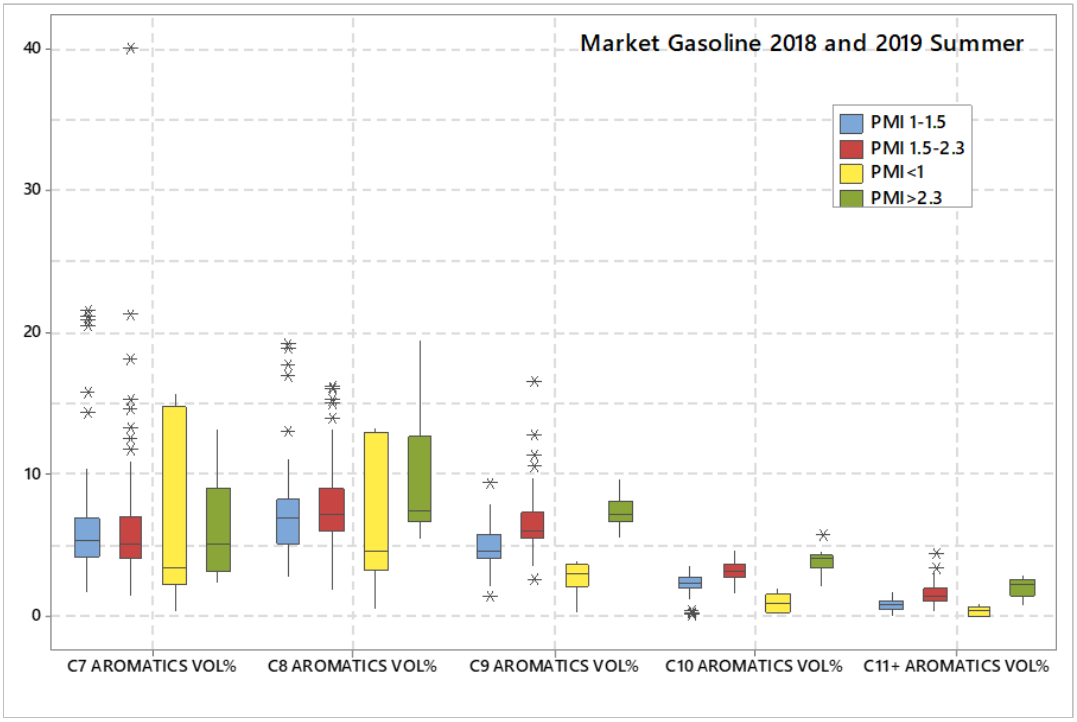

Figure 2.3. Boxplot of aromatics volume percent from US market summer gasoline 2018 and 2019.

The ten highest PMI fuels from these surveys were investigated further to characterize the PMI contributions by hydrocarbon class and within the aromatic fraction. Table 2.2 shows the distribution of hydrocarbon groups in each of the samples as well as averages by class and their corresponding PMI contributions. Table 2.3 shows that the majority of PMI for these high PMI fuels is from aromatic hydrocarbons. Table 2.4 and Table 2.5 show the distribution of aromatic hydrocarbons by carbon number in each of the samples as well as averages by carbon number and their corresponding PMI contributions.

Table 2.2. Hydrocarbon content (vol%) for samples from 2018-2019 with the ten highest PMIs.

Vol%	G180713-03	G180704-10	G180725-07	G180710-18	G180725-12	G180719-15	G180714-09	G180717-03	G190722-08	G190711-07
P	8.51	11.83	12.31	15.14	11.20	14.62	11.30	12.90	14.98	13.85
I	46.52	32.32	36.44	32.76	33.72	33.17	36.69	27.29	36.60	34.45
O	1.90	10.36	10.26	6.79	9.50	9.06	6.64	6.19	7.80	5.85
N	5.35	9.32	7.74	7.10	6.89	6.80	11.26	3.14	7.11	8.82
A	37.70	26.13	23.21	28.13	28.49	25.64	24.01	40.58	23.20	26.96
Ethanol	0.00	9.94	9.90	9.98	10.00	9.91	9.97	9.77	9.50	9.57
X	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.04
Unknown	0.03	0.12	0.15	0.10	0.21	0.82	0.13	0.04	0.80	0.47
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 2.3. PMI and percentage contributions by hydrocarbon group for samples from 2018-2019 with the ten highest PMIs.

PMI	G180713-03	G180704-10	G180725-07	G180710-18	G180725-12	G180719-15	G180714-09	G180717-03	G190722-08	G190711-07
P	0.017	0.030	0.030	0.029	0.029	0.024	0.023	0.013	0.033	0.021
I	0.102	0.086	0.093	0.076	0.098	0.087	0.099	0.051	0.087	0.088
O	0.007	0.024	0.029	0.021	0.023	0.026	0.025	0.009	0.022	0.018
N	0.035	0.049	0.049	0.042	0.048	0.043	0.068	0.021	0.044	0.051
A	1.952	2.133	2.050	2.148	2.386	2.261	2.107	2.057	2.018	2.194
Ethanol	0.000	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
X	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	2.113	2.334	2.263	2.330	2.597	2.455	2.334	2.163	2.216	2.384
PMI%	G180713-03	G180704-10	G180725-07	G180710-18	G180725-12	G180719-15	G180714-09	G180717-03	G190722-08	G190711-07
P	0.819	1.291	1.347	1.249	1.125	0.984	0.998	0.605	1.478	0.861
I	4.849	3.680	4.102	3.280	3.755	3.542	4.250	2.344	3.935	3.709
O	0.331	1.033	1.265	0.896	0.898	1.078	1.062	0.435	1.011	0.759
N	1.662	2.094	2.148	1.820	1.858	1.768	2.901	0.975	1.984	2.138
A	92.338	91.375	90.592	92.224	91.891	92.124	90.256	95.090	91.052	92.033

Table 2.4. PMI and percentage contributions by aromatic carbon number for samples from 2018-2019 with the ten highest PMIs.

PMI	G180713-03	G180704-10	G180725-07	G180710-18	G180725-12	G180719-15	G180714-09	G180717-03	G190722-08	G190711-07
A6	0.004	0.003	0.003	0.008	0.002	0.005	0.004	0.003	0.614	1.167
A7	0.163	0.073	0.034	0.080	0.056	0.041	0.058	0.115	2.912	6.006
A8	0.349	0.214	0.193	0.220	0.180	0.191	0.169	0.532	8.321	8.396
A9	0.431	0.308	0.380	0.354	0.503	0.406	0.334	0.391	7.832	7.470
A10	0.373	0.516	0.505	0.513	0.634	0.573	0.540	0.383	5.098	5.305
A11	0.186	0.518	0.398	0.460	0.426	0.531	0.479	0.190	1.608	1.981
A12	0.193	0.459	0.369	0.374	0.334	0.464	0.481	0.169	1.290	1.426
A13	0.194	0.042	0.150	0.139	0.253	0.046	0.042	0.262	0.060	0.042
A14	0.058	0.000	0.016	0.000	0.000	0.004	0.000	0.011	0.005	0.000
A15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PMI%	G180713-03	G180704-10	G180725-07	G180710-18	G180725-12	G180719-15	G180714-09	G180717-03	G190722-08	G190711-07
A6	0.225	0.132	0.143	0.393	0.070	0.209	0.186	0.143	2.213	3.671
A7	8.342	3.410	1.672	3.737	2.331	1.830	2.768	5.599	10.497	18.891
A8	17.861	10.036	9.430	10.261	7.523	8.441	8.027	25.876	29.996	26.408
A9	22.094	14.451	18.546	16.459	21.084	17.943	15.862	19.018	28.234	23.496
A10	19.135	24.179	24.654	23.857	26.564	25.353	25.625	18.633	18.378	16.686
A11	9.547	24.294	19.435	21.427	17.837	23.495	22.732	9.247	5.797	6.231
A12	9.878	21.510	18.018	17.414	13.986	20.540	22.813	8.229	4.650	4.485
A13	9.928	1.989	7.321	6.452	10.605	2.031	1.987	12.730	0.216	0.132
A14	2.991	0.000	0.781	0.000	0.000	0.159	0.000	0.525	0.018	0.000
A15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 2.5. Aromatic hydrocarbon content (vol%) for samples from 2018-2019 with PMI 2.3-2.8 and corresponding PMI contribution.

Group\ID	G180713-03	G180704-10	G180725-07	G180710-18	G180725-12	G180719-15	G180714-09	G180717-03	G190722-08	G190711-07	Average	Stdev
A10	3.45	4.26	4.21	4.40	5.91	4.81	4.46	3.68	4.20	4.44	4.38	0.66
A11	0.61	1.53	1.15	1.24	1.40	1.49	1.37	0.50	1.27	1.58	1.21	0.37
A12	0.37	1.11	0.90	0.92	0.86	1.36	1.21	0.26	1.05	1.17	0.92	0.35
A13	0.10	0.03	0.07	0.07	0.12	0.03	0.02	0.12	0.04	0.03	0.06	0.04
A14	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A6	0.62	0.40	0.41	1.18	0.24	0.66	0.55	0.42	0.51	0.99	0.60	0.29
A7	11.71	5.19	2.42	5.71	3.98	2.92	4.13	8.34	2.47	5.16	5.20	2.90
A8	12.64	7.73	6.89	7.91	6.45	6.77	5.98	19.49	7.05	7.21	8.81	4.19
A9	8.20	5.89	7.16	6.71	9.52	7.61	6.29	7.76	6.60	6.38	7.21	1.09
>A10 (11-14)	1.08	2.66	2.12	2.23	2.38	2.88	2.60	0.89	2.36	2.78	2.20	0.68
PEI	1.45	1.73	1.56	1.64	1.87	1.88	1.68	1.51	1.62	1.79	1.67	0.15
PMI	2.11	2.33	2.28	2.33	2.60	2.45	2.33	2.16	2.22	2.38	2.32	0.14
PMI Aromatics	1.95	2.13	2.05	2.15	2.39	2.26	2.11	2.06	2.02	2.19	2.13	0.13
PMIa/PMI	92.34	91.38	90.59	92.22	91.89	92.13	90.25	95.09	91.05	92.03	91.90	1.33

2.1.2. Test Fuel Matrix - Blending Approach

The formulation of the Base Fuel was developed first. The intent was to replicate the composition and properties of a typical US summer gasoline with special emphasis on the distribution of aromatic compounds within the distillation range of this fuel. The first hand-blend of this fuel matched the aromatics distribution by Carbon Number (C#) provided in Table 2.6.

Fuel A, the highest PMI fuel, was prepared by adding to the Base Fuel a blend consisting of ExxonMobil Aromatic 150 and Aromatic 200 refinery stream products, which consist of specific boiling-range cuts of reformate. The ratio of these two streams was adjusted to ensure the target PMI level of 2.7 ± 0.1 and an aromatics profile representative of high-PMI market fuels. The quantity of the blend added to the Base Fuel was 3.1%v, so that its content in Fuel A equals exactly 3.0 %v.

Fuels B, C and D were prepared by adding 3.1%v of C7-C9 aromatics, 3.1%v of refinery-sourced alkylate, and 6%v of fuel grade ethanol to the Base Fuel, respectively.

Hand-blends were evaluated using the following methods: ASTM D4052 density, D4815 ethanol, D86 distillation, D5191 DVPE (EPA equation), hydrocarbon composition and PM Index by Gage DHA, D6550 olefins, D5453 sulfur, D2699 & D2700 octane numbers and D5188 $T_{(V/L=20)}$. The following additional requirements were included in the specifications:

- Convert ethanol results to vol. % per Section 14.3 of D4815.
- Use only OptiDist or equivalent stills to generate D86 distillation data. Stills should measure charge volume in the receiving cylinder. In addition, report distillation data in 1%v increments.
- Calculate D5191 DVPE using the EPA equation per Code of Federal Regulations (CFR), Title 40, Part 80.46. Report total pressure measured during the test alongside the DVPE.
- Sulfur adjustments should be made using benzothiophene, t-butyl disulfide, or a three-component sulfur mixture containing 4.3 mass % dimethyl disulfide, 22.8 mass % thiophene, and 72.9 mass % benzothiophene.

Table 2.6. Hand-blend fuel specifications.

Parameter	Base Fuel (Typical US gasoline)	Fuel A (Base Fuel w/3.1%v of C11+ aromatics)	Fuel B (Base Fuel w/3.1%v of C7-C9 aromatics)	Fuel C (Base Fuel w/3.1%v alkylate)	Fuel D (Base Fuel w/6%v EtOH)
Density, 60ºF (D4052)	Report	Report	Report	Report	Report
PM Index (Gage DHA)	1.6 ± 0.1	2.7 ± 0.1	Report	Report	Report
Ethanol (D4815)	9.8 ± 0.2 %v	9.5 ± 0.2 %v	~ Fuel A	~ Fuel A	14.9 ± 0.2 %v
Total Content of Oxygenates Other Than Ethanol (D4815)	0.1 %v max				
Oxygen (D4815)	Report in %m	Report in %m	Report in %m	Report in %m	Report in %m
(R+M)/2 (D2699, D2700)	87.3 ± 0.3	Report	Report	Report	Report
Sensitivity (D2699, D2700)	> 7.5				
DVPE (D5191, EPA	All fuels expected to remain in 8.95 ± 0.25 psi range				
T10 (D86)	≤ 149 ºF				
T50 (D86)	185 ± 10 ºF	Report	Report	Report	Report
T90 (D86)	320 ± 10 ºF	Report	Report	Report	Report
Distillation End Point (D86)	≤ 437 ºF				
Distillation Residue (D86)	≤ 1.3 %v				
Total Aromatics (Gage DHA)	24.5 ± 2 %v	Fuel A + 2.2 %v	Fuel A + 2.2 %v	Fuel A – 0.7 %v	Fuel A – 1.4 %v
Benzene (Gage DHA)	0.6 ± 0.2 %v	~ Base Fuel	~ Base Fuel	~ Base Fuel	~ Base Fuel
Toluene (Gage DHA))	6.1 ± 1.0 %v	Report	Report	Report	Report
C8 Aromatics (Gage DHA)	7.4 ± 1.0 %v	Report	Report	Report	Report
C9 Aromatics (Gage DHA)	5.5 ± 1.0 %v	Report	Report	Report	Report
C10 Aromatics (Gage DHA)	2.7 ± 1.0 %v	Report	Report	Report	Report
C11+ Aro. (Gage DHA)	1.2 ± 0.5 %v	Report	Report	Report	Report
Olefin Content (D6550)	7 ± 3 %m	Report	Report	Report	Report
Sulfur Content (D5453)	7 ± 3 mg/kg	7 ± 3 mg/kg	Report	Report	Report
$T_{(V/L=20)}$ (D5188)	≥ 116 ºF	≥ 116 ºF	≥ 116 ºF	≥ 116 ºF	≥ 116 ºF
Drivability Index (D4814)	≤ 1250	≤ 1250	≤ 1250	≤ 1250	≤ 1250

2.1.3. Test Fuel Matrix – Final Confirmation

Once the analytical results generated by the fuel blender indicated that hand-blends met requirements of the specifications provided in Table 2.6, the blender submitted a sample of each hand blend to the General Motors Pontiac chemistry laboratory and the U.S. EPA chemistry laboratory for additional confirmation of the following analyses: ASTM D4052 density, D5599 ethanol, D86 distillation, D5191 DVPE (EPA equation), D6550 olefins, D5453 sulfur, D2699/D2700 octane numbers and D5188 $T_{(V/L=20)}$. After confirming all tests were within acceptable ranges, the project sponsors approved production of bulk blends for shipment to the test labs. A detailed list of fuel properties measured from the bulk blends is given in Table 2.7.

Table 2.7. Final fuel property results.

Parameter	Unit	Method	Blending Tolerance	Base Fuel (Typical regular-grade gasoline) Specification	Base Fuel Average	Fuel A (Base Fuel w/3.1 vol.% of C10+ Aromatics) Specification	Fuel A Average	Fuel B (Base Fuel w/3.1 vol.% of C7-C9) Specification	Fuel B Average	Fuel C (Base Fuel w/3.1 vol.% of alkylate) Specification	Fuel C Average	Fuel D (Base Fuel w/6 vol.% of ethanol) Specification	Fuel D Average
Density @ 60ºF	g/cm^3	D4052	-	-	0.7428	-	0.7490	-	0.7477	-	0.7420	-	0.7457
Specific Gravity @ 60ºF	-	D4052	-	-	0.7435	-	0.7497	-	0.7484	-	0.7428	-	0.7465
PMI Index by Gage DHA	-	Gage DHA	± 0.1	1.5	1.49	2.66	2.72	1.58	1.53	1.46	1.50	1.42	1.41
Ethanol	vol. %	D4815	± 0.2	10	9.54	9.7	9.27	9.7	9.24	9.7	9.23	14.9	14.75
Other Oxygenates	vol. %		maximum	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0
Oxygen	mass %		-	-	3.54	-	3.43	-	3.43	-	3.42	-	5.48
RON	-	D2699	-	-	91.1	-	91.4	-	91.7	-	91.2	-	93.8
MON	-	D2700	-	-	83.2	-	83.5	-	83.7	-	83.7	-	84.6
(R + M)/2	-	D2699/D2700	± 0.3	87.2	87.2	87.4	87.5	87.5	87.6	87.2	87.4	89.2	89.2
Sensitivity	-		-	-	7.9	-	7.9	-	7.9	-	7.5	-	9.2
DVPE	psi	D5191 (EPA)	± 0.2	9.0	9.2	8.6	9.1	8.7	8.9	8.7	9.0	8.7	9.1
Distillation													
IBP	ºF	D86	-	-	95.1	-	95.6	-	96.1	-	95.5	-	96.0
T5			-	-	117.0	-	118.7	-	118.9	-	118.3	-	119.4
T10			± 5	127.6	125.0	128.6	126.5	128.9	127.2	128.1	126.2	129.3	127.2
T20			-	-	135.6	-	137.2	-	137.7	-	136.6	-	137.9
T30			± 5	146.1	144.9	147.3	146.4	147.5	146.9	146.5	145.8	148.3	147.2
T40			-	-	152.6	-	154.7	-	155.6	-	153.5	-	155.0
T50			± 5	196.7	192.9	207.2	205.1	206.3	204.8	202.1	199.8	161.7	161.5
T60			-	-	232.8	-	240.0	-	237.7	-	232.8	-	218.9
T70			± 5	256.8	255.5	264.3	264.6	260.0	259.7	255.1	255.7	253.6	252.9
T80			-	-	280.7	-	292.8	-	283.2	-	279.9	-	278.6
T90			± 5	313.9	312.0	331.5	331.9	313.3	315.6	314.1	312.0	311.6	311.3
T95			-	-	344.1	-	367.9	-	345.4	-	344.4	-	342.3
FBP			maximum	437	380.1	437	420.3	437	382.0	437	383.2	437	382.2
Residue, vol.%	%v		maximum	1.3	1.0	1.3	1.1	1.3	1.0	1.3	1.0	1.3	1.0
Recovery			-	-	97.4	-	97.9	-	97.8	-	98.1	-	98.1
Loss			-	-	1.5	-	1.5	-	1.6	-	1.5	-	1.5
Total Aromatics	%v	(Gage DHA)	± 1	25.0	24.6	27.3	26.8	27.5	27.3	24.2	24.1	23.6	23.2
Benzene			± 0.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Toluene			± 1	6.3	6.2	6.1	6.0	7.1	7.3	6.1	6.0	7.9	5.9
C8 Aromatics			± 1	8.1	8.1	7.9	7.8	9.0	8.9	7.8	7.9	5.9	7.6
C9 Aromatics			± 1	5.5	5.3	5.4	5.2	6.3	6.0	5.4	5.2	5.2	5.0
C10 Aromatics			± 1	3.4	3.3	4.9	4.7	3.5	3.3	3.3	3.2	3.2	3.0
C11+ Aromatics			± 0.3	1.1	1.2	2.4	2.5	1.1	1.2	1.1	1.2	1.0	1.2
PM Index by D6729	-	D6729	-	-	1.43	-	2.28	-	1;46	-	1.44	-	1.37
Total Aromatics	%v		-	-	25.1	-	27.7	-	27.3	-	24.8	-	24.1
Benzene			-	-	0.6	-	0.6	-	0.6	-	0.6	-	0.6
Toluene			-	-	6.7	-	6.5	-	7.8	-	6.3	-	6.4
C8 Aromatics			-	-	7.9	-	7.7	-	8.6	-	7.8	-	7.5
C9 Aromatics			-	-	5.4	-	5.4	-	6.0	-	5.4	-	5.2
C10 Aromatics			-	-	3.0	-	4.5	-	3.0	-	3.1	-	2.9
C11+ Aromatics			-	-	1.6	-	3.0	-	1.4	-	1.6	-	1.4
PM Index by D6730-1X	-	D6730-1X	-	-	1.48	-	0.00	-	1.53	-	1.45	-	1.41
Total Aromatics	%v		-	-	24.7	-	0.0	-	27.4	-	24.0	-	23.4
Benzene			-	-	0.6	-	0.0	-	0.6	-	0.6	-	0.6
Toluene			-	-	6.3	-	0.0	-	7.4	-	6.1	-	5.9
C8 Aromatics			-	-	7.9	-	0.0	-	8.8	-	7.7	-	7.6
C9 Aromatics			-	-	5.3	-	0.0	-	6.0	-	5.2	-	5.1
C10 Aromatics			-	-	3.0	-	0.0	-	3.0	-	2.9	-	2.8
C11+ Aromatics			-	-	1.5	-	0.0	-	1.5	-	1.5	-	1.5
Olefins	%m	D6550	± 3	7	8.7	7	8.5	7	8.7	7	8.4	7	8.1
Sulfur	mg/kg	D5453	± 3	7	6.3	7	6.0	7	6.0	7	6.1	7	5.8
Carbon (Part of D4809)	mass %	D5291	-	-	82.62	-	82.98	-	82.99	-	82.82	-	80.86
Hydrogen (Part of D4809)	mass %	D5291	-	-	13.72	-	13.49	-	13.44	-	13.70	-	13.61
Carbon	mass %	D3343M	-	-	82.70	-	82.98	-	82.96	-	82.71	-	80.99
Hydrogen	mass %	D3343M	-	-	13.64	-	13.5	-	13.47	-	13.81	-	13.49
Water Content	mg/kg	E1064	-	-	1315	-	1259	-	1256	-	1314	-	1925
Lead	g/l	D3237	-	≤ 0.013 g/l	< 0.0027	≤ 0.013 g/l	< 0.0027	≤ 0.013 g/l	< 0.0027	≤ 0.013 g/l	< 0.0027	≤ 0.013 g/l	< 0.0027
Net Heat of Combustion (D240)	MJ/kg	D240	-	-	41.58	-	41.63	-	41.56	-	41.78	-	40.74
Net Heat of Combustion - D1319	MJ/kg	D3338	-	-	41.36	-	41.34	-	41.31	-	41.79	-	40.40
Oxidation Stability	minute	D525	minimum	240	> 1,000	240	> 1000	240	> 1000	240	> 1000	240	> 1000
Copper Strip Corrosion, 3h at 122ºF	-	D130	maximum	No. 1	1A	No. 1	1A	No. 1	1A	No. 1	1A	No. 1	1A
Solvent-Washed Gum Content	mg/100 ml	D381	maximum	5	< 0.5	5	< 0.5	5	< 0.5	5	< 0.5	5	< 0.5
$T_{(V/L20)}$	ºF	D5188	minimum	116	128.7	116	129.7	116	130.3	116	129.8	116	129.3
Driveability Index	-	D4814	maximum	1250	1101	1250	1159	1250	1143	1250	1123	1250	1022

2.2. Test Vehicles

The study included 10 vehicles selected in coordination with all 9 program participants. The principal guideline adopted for vehicle selection was to develop a test fleet representative of propulsion system technologies prevalent in the current on-road, light duty vehicle fleet. To this end, a concerted effort was made to select test vehicles that covered a range of model years (2015-2022) and different emissions requirements (Tier 2 and Tier 3). Additional vehicle selection considerations included: popular U.S. sales models, variety of manufacturers, vehicle mileage, body type (sedan/SUV/Truck), transmission (CVT/Automatic), and engine design features - displacement, fuel injection (DI/PFI), aspiration (natural/forced), valvetrain, and EGR. All participants sourced and inspected the vehicles they tested, with one participant testing two vehicles and the other eight participants testing one vehicle each. A list of characteristics of the test vehicles is provided in Table 2.8.

Table 2.8. Vehicle test fleet.

Make	Honda	Toyota	Ford	GMC	Hyundai	Jeep	Toyota	Nissan	Honda	Dodge
Model	Civic	Camry	Expedition	Terrain	Tucson	Renegade	RAV4 HV	Altima	Ridgeline	Ram 1500
MY	2016	2018	2015	2021	2022	2020	2019	2020	2020	2021
Odometer [miles]	10,297	6,951	32,699	4,490	4,598	~3,000		4,500		2,990
Tier/Bin	IT3B125	T3B30	T2B5, LDT4	T3B30	T3B70	T3B50	T3B30	T3B30	T3B125	T3B70
Engine Displacement [l]	1.5	2.5	3.5	1.5	2.5	1.3	2.5	2.5	3.5	5.7
Turbo	x	-	x	x	-	x	-	-	-	-
PFI	-	x	-		x	-	x	-	-	x
GDI	x	x	x	x	x	x	x	x	x	-
EGR	-	x	-	-	x	-	x	-	x	-
Atkinson/Miller	x	x	-	-	-	-	x	-	-	-
Transmission	CVT	Auto-8	Auto-6	Auto-9	Auto-8	Auto-9	CVT - 6	CVT	Auto-9	Auto-8
Body type	Sedan	Sedan	SUV	SUV	SUV	SUV	SUV	Sedan	Truck	Truck
Fuel Tank Capacity [gal]	12.4	16	28	15.6	14.3	15.3	14.5	16.2	19.5	21.6
City FE [mpg]	27	32	14	24	24	23	41	26	22	15
Recommended Octane [AKI]	≥87	≥87	87	87	87	87	87	87	87	87

2.3. Emissions Testing: Procedures and Guidelines

Vehicle emissions testing was conducted at nine different test sites, one per each program participant. Some labs used the same test cell and driver for all tests, while others used multiple cells and drivers. At least one lab used a robotic vehicle operator.

As noted in Section 3.2, one participant tested two vehicles while the remaining eight participants tested one vehicle each. Emissions testing at all nine test facilities was conducted in accordance with measurement instruments, analytical gas specifications, chassis dynamometer specifications, vehicle preparation and test procedures in compliance with CFR Title 40 Part 1066. All participating test facilities are experienced in conducting fuel economy and tailpipe emissions certification testing.

As described in Section 2, the primary focus of this test program was to evaluate the impact on tailpipe PM emissions of replacing the heavy hydrocarbons contributing to the tail of the gasoline distillation curve with lower PMI components. With this program objective in mind and the goal of reducing variability in the measured emissions data, all program participants agreed to follow common guidelines and test procedures, which are outlined in the following sub-sections.

2.3.1. Test Cycles

As per the Code of Federal Regulation (CFR) Title 40 Part 86 Section 86.1181-04 (Tier 2) and 86.1181-17 (Tier 3), exhaust emissions standards for Particulate Matter are defined based on the FTP (Figure 2.4) and the US06 (Figure 2.5) drive cycles. Consequently, the PM emissions data available in literature and EPA databases, largely focus on the FTP and US06 drive cycles. Considering the CFR requirements and the availability of historical PM emissions data for the FTP and US06 drive cycles, the current study also focused on collecting emissions data for the two aforementioned test cycles.

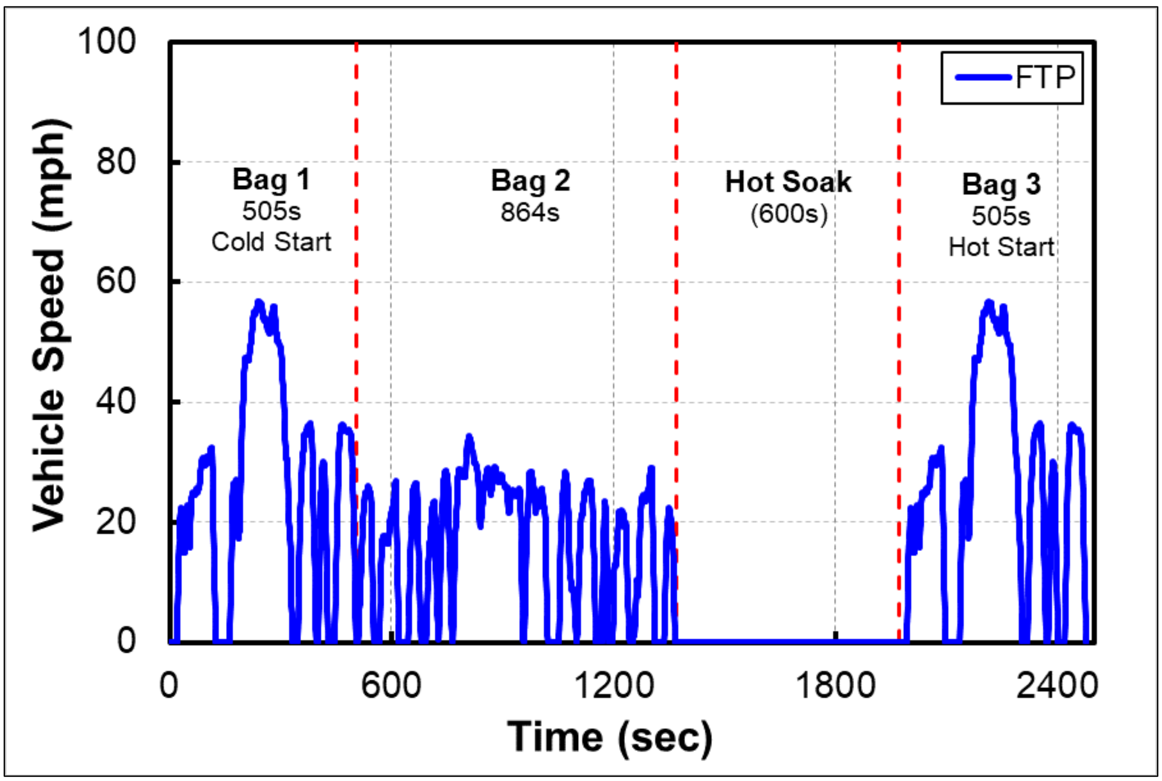

Figure 2.4. U.S Federal Test Procedure (FTP).

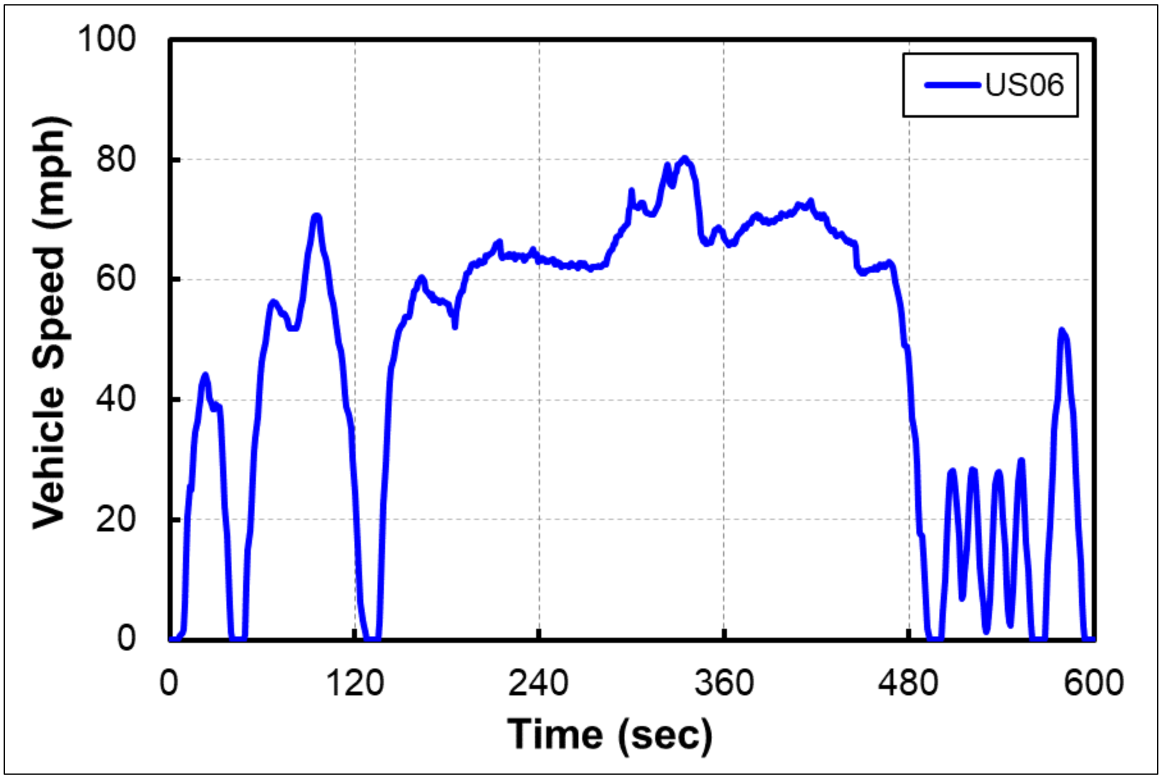

Figure 2.5. Supplemental FTP or US06.

2.3.2. Dilution Tunnel Cleanliness

Most of the participating test facilities were supporting other programs in parallel, whereby the background PM level in the dilution and sampling system could be varying over the course collecting data for this study. To address such concerns, the procedure outlined in Table 2.9 was recommended for tracking background levels. This procedure was implemented by some participants, while others tracked background using procedures already in place at their labs. Additionally, the participating labs were encouraged to schedule drive cycles with higher loads, such as US06, in the test cell prior to test execution for the current study. The premise of this recommendation was that high-temperature and/or flow operations would tend reduce the likelihood of tailpipe PM measurements being contaminated by residual PM in the dilution tunnel.

Table 2.9. Tunnel background PM sampling procedure, to be performed once a week.

Step	Description
1	Load a preconditioned Teflon filter into the PM sampler and perform a leak check.
2	Cap the inlet of vehicle exhaust into the CVS system and run Phase 1 of the FTP-75 test cycle (the 505) while sampling PM.
3	Report background filter number, test number as well as the accumulated filter weight in mg and mg/mile to the test engineer.

2.3.3. Drivers
While most test facilities used human drivers, a couple of the test facilities used robot drivers for executing the vehicle test plan. In order to minimize test-to-test variability, all program participants were encouraged to avoid switching drivers between tests. Where possible, the program participants attempted to retain the same driver from their respective test facilities for all the tests. However, scheduling requirements at the respective test facilities did not always permit the use of the same driver.

2.3.4. Test Fuel Sequence
For each test vehicle, the fuel sequence started and ended with Fuel A to allow for a means to check for drift in the measurements over the duration of the test program. However, to minimize the risk of the study's conclusions being influenced by the order in which the fuels were tested, the sequence in between the first and last fuel (Fuel A) was randomized for each vehicle, as illustrated in Table 2.10. Four vehicles were not tested on Base fuel.

Table 2.10. Fuel testing sequence for each vehicle.

Make	Honda	Toyota	Ford	GMC	Hyundai	Jeep	Toyota	Nissan	Honda	Dodge
Model	Civic	Camry	Expedition	TERRAIN	Tucson	Renegade	RAV4 HV	Altima	Ridgeline	Ram 1500
MY	2016	2018	2015	2021	2022	2020	2019	2020	2020	2021
Fuel Test Sequence	ACB(Base)DA	ABD(Base)CA	ADB(Base)CA	ACDB(Base)A	ACBDA	ABCDA	ADCBA	ABDCA	AD(Base)CBA	ABD(Base)CA

2.3.5. Vehicle Fuel Change and Test Preparation
In view of the current study's focus of measuring changes in tailpipe emissions from small changes in fuel composition, special care was taken to avoid the contamination of measurements for one fuel with another. To this end, all program participants adhered to the fuel change and vehicle preparation procedure outlined in Table 2.11.

Table 2.11. Fuel change and vehicle preparation procedure.

Step	Description
1	With the ignition key in OFF position, drain vehicle fuel tank to empty.
2	Fill fuel tank to 20% with next test fuel in sequence.
3	With the ignition key in OFF position, drain vehicle fuel again to empty.
4	Fill the fuel tank to 55%.
5	Run a LA4 (UDDS) prep cycle followed by a HWFETx2 prep cycle and a US06x2 prep cycle. Following the US06 cycle, allow the vehicle to idle in neutral for two minutes, then shut the engine off in preparation for the soak. Note: Program participants are encouraged to log the following OBD2 parameters during both parts of LA4 and US06 prep cycles for use in quality control of emissions test results: Engine rpm, vehicle speed, engine load, short term fuel trim – bank 1, long term fuel trim – bank 1, MIL status, absolute throttle position, engine coolant temperature, fuel/air commanded equivalence ratio, manifold air flow, spark timing, PID $42 control module voltage, purge duty cycle.
6	Move vehicle to soak area without starting the engine (or leave on dyno for soak).
7	Soak vehicle at nominal 75°F for a minimum of 12-28 hours. Record soak temperature and duration. Note: During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device.

2.3.6. Emissions Testing Procedures

To minimize lab-to-lab variability in emissions measurements, a detailed step-by-step vehicle test procedure was defined at the start of the study. All program participants strictly adhered to the procedure outlined in Table 2.12.

Table 2.12. Vehicle test procedure.

Step	Description
1	Following a soak of 12-28 hours at nominal 75°F, perform the following: 1. Check vehicle diagnostic trouble codes. Notify project engineer if any are detected. 2. Check tire pressure and adjust, if necessary. Note: Record soak temperature and duration and include in test report.
2	Move vehicle to test area without starting engine.
3	Perform FTP-75 (3 phase) test followed by a US06x2 test. Collect separate PM samples for each of the three phases of the FTP-75 test. Similarly, collect separate PM samples for Highway and City portions of the US06 test. However, sampling PM through the whole FTP-75 or US06 test (with appropriate adjustments in flowrate) will be treated as equivalent in this study. Following the US06 cycle, allow the vehicle to idle in neutral for two minutes, then shut the engine off in preparation for the soak.
4	Move vehicle to soak area without starting the engine (or leave on dyno for soak).
5	Park vehicle in soak area for 12-28 hours at nominal 75°F. Note: During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device.
6	Move vehicle to test area without starting the engine. Record soak temperature and duration and include in test report.
7	Repeat Steps 3-7 a minimum of 4, but preferably 6 times. Note: If 28 hour soak has been exceeded between tests, perform the following as early as possible: 1. Fill the fuel tank to 40% of tank volume with the same fuel. 2. Run a LA4 (UDDS) prep cycle followed by a US06x2 prep cycle. 3. Check vehicle diagnostic trouble codes. Notify project engineer if any are detected. 4. Park vehicle in soak area for 12-28 hours at nominal 75°F. Note: During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device 5. Following the soak, check tire pressure and adjust, if necessary, and proceed to Step 3.

2.3.7. Particulate Matter (PM) Measurement

The following subsections briefly describe the PM measurement techniques used by the program participants during data collection for this study.

2.3.7.1. Gravimetric

Gravimetric PM mass emission measurements were made in all facilities (with one exception) by sampling the tunnel-diluted exhaust using Teflon filters following Code of Federal Regulations Title 40, Part 1065. Labs used either a single filter for all drive cycle phases (bags) or separate filters for each phase. Blank filters of the tunnel dilution air were collected and analyzed, but no blank correction was applied to the results.

2.3.7.2. OC/EC

In one facility, particulate mass was determined using an organic carbon/elemental carbon (OC/EC) method. PM was captured from diluted exhaust on a prebaked quartz filter. Multiple cut-outs from the filter were analyzed by thermal analysis using a Horiba MEXA 1370PM particulate analyzer. CO_2 measured after heating to 980°C, first under nitrogen and then with oxygen present, is converted to masses of organic carbon and elemental carbon, respectively, and their sum provides a measure of total PM [12]. Blank filters (with and without sampling the dilution air) were collected and analyzed, but no blank correction was applied to the results.

2.3.7.3. AVL MicroSoot Sensor (MSS)

In addition to Teflon filter based gravimetric measurements, all program participants were encouraged to collect PM data using an MSS, with the objective of helping validate trends observed in filter PM data. However, not all participating test facilities were adequately equipped for making MSS measurements. Consequently, MSS data is not available for all vehicles and has been used in this study only for diagnostic purposes where available.

2.4. Vehicle Emissions Results

The following subsections present detailed data review and statistical analysis for PM, NOx, NMOG, and CO_2 emissions. All the analyses used FTP and US06 cycle composite values with phase weighting as described in 40 CFR Part 1065/1066. Observations of statistical significance for model parameters and comparisons are based on the $p \leq 0.05$ criterion.

Two levels of results are presented for each cycle and emission. The first is a PM Index (PMI) model that draws information from across all the test fuels. This result is of interest because PMI was a primary design parameter for the fuel set and is a good predictor of PM emissions. However, this approach does not control for (attempt to separate) potential impacts of other fuel parameters such as ethanol content or total aromatics. The second level of results is a set of fuel-to-fuel comparisons that evaluate the overall impact of each formulation. This approach fully quantifies the differences between each fuel but doesn't attempt to associate it with any particular parameter. Results for additional emissions are provided in Appendix A.

2.4.1. Particulate Emissions

The particulate matter (PM) results presented in this report were not background corrected, meaning there was no subtraction of filter weights collected from background air or blank tests. During the test program, each lab followed its normal practices to monitor background PM levels and ensure good data quality in the reported PM values.

The sections that follow provide a detailed statistical analysis of the PM emissions data both for the FTP cycle and the US06 cycle. The results are also summarized at a high level in Figure 2.6 and Figure 2.7. These figures show the percent reduction in PM emissions for each vehicle (and for the average of the test vehicle fleet) when switching from fuel A (containing 7.4 %v C10+ aromatics) to fuels B, C, D, and the base fuel (each containing

4.2-4.5 %v C10+ aromatics). For these fuels with reduced C10+ aromatic content, the average PM emission reductions were 35-45% on the FTP Composite cycle and 20-25% on the US06 cycle for the 10 vehicles in this study.[1]

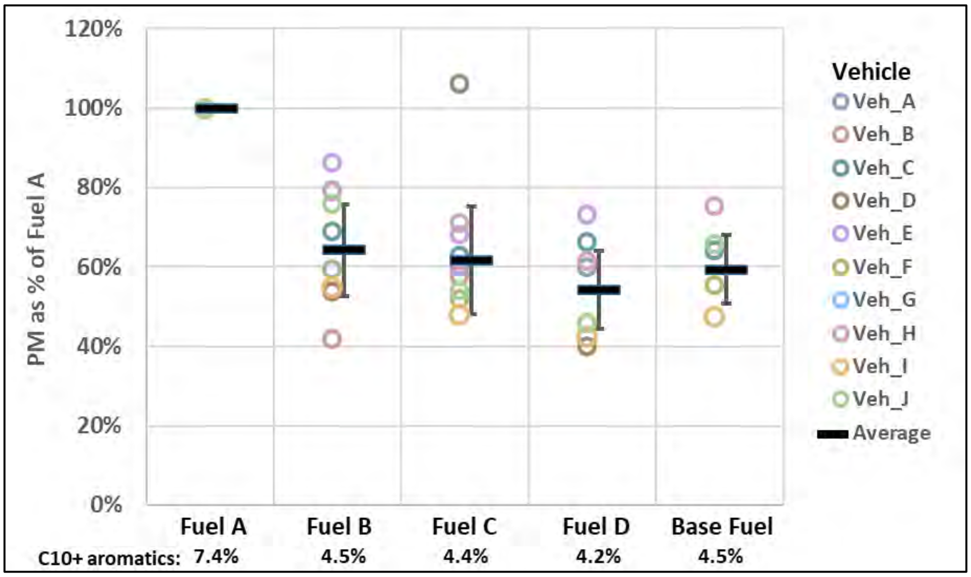

Figure 2.6. Summary of PM emissions reductions for the FTP cycle for each test fuel (relative to Fuel A), shown by vehicle and for the test fleet average with 95% confidence interval.

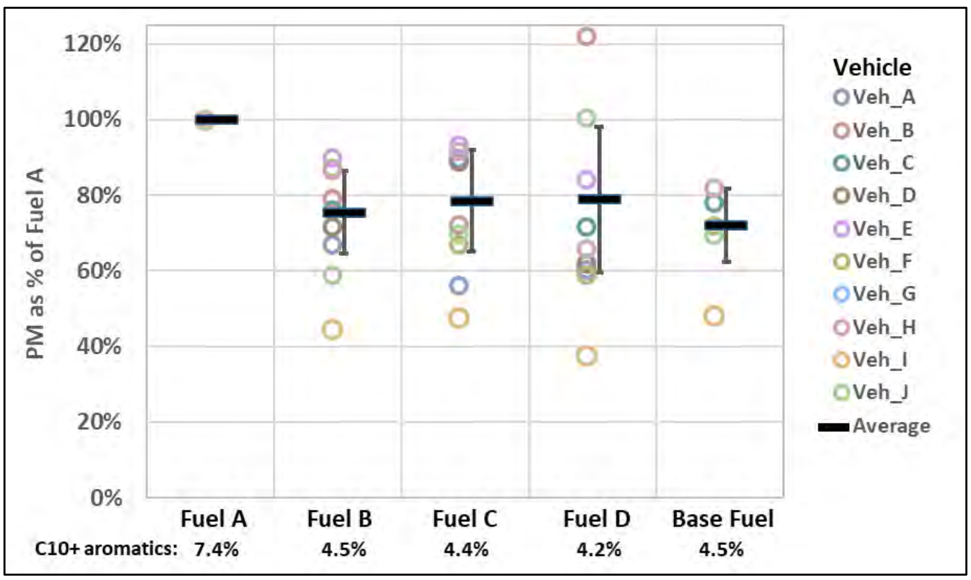

Figure 2.7. Summary of PM emissions reductions for the US06 cycle for each test fuel (relative to Fuel A), shown by vehicle and for the test fleet average with 95% confidence interval.

Table 2.13 presents percent-PM-emission per percent-PMI sensitivities (ratios) by test cycle and vehicle. The vehicles are sorted from smallest to largest effect for the FTP and span a range of approximately 1.0 to 2.2. For the US06 cycle, the range is approximately 0.5 to 2.3 if the value for Veh_G is excluded. (A review of data for

[1] Fuel C results for Veh_D indicate an upward shift from Fuel A, in contrast to all other test vehicles. While these results are unexpected, no anomalies were reported in the test procedures or vehicle operation for those measurements, thus they were retained in the dataset.

Veh_G finds it has a relatively low sensitivity to PMI over the US06, which allowed a few influential measurements to tip the average value in the opposite direction of the other vehicles.)

Table 2.13. Percent-PM-emissions per percent-PM-Index sensitivities by test cycle and vehicle.

	Veh_H	Veh_E	Veh_A	Veh_C	Veh_D	Veh_J	Veh_B	Veh_F	Veh_I	Veh_G
FTP	1.01	1.08	1.20	1.21	1.34	1.47	1.55	1.66	1.83	2.15
US06	0.51	0.44	1.67	0.80	1.15	1.42	0.64	1.22	2.27	-0.12

FTP Cycle Results

Figure 2.8 and Figure 2.9 provide a graphical overview of the measurements collected on the FTP cycle, grouped by vehicle, on linear and log scales, respectively. The axis label "index" refers to the count of individual observations. For the FTP cycle, the vehicle means range from under 0.5 mg/mi to about 7 mg/mi, with individual vehicles spanning up to 5 mg/mi over their fuel and replicate sets.

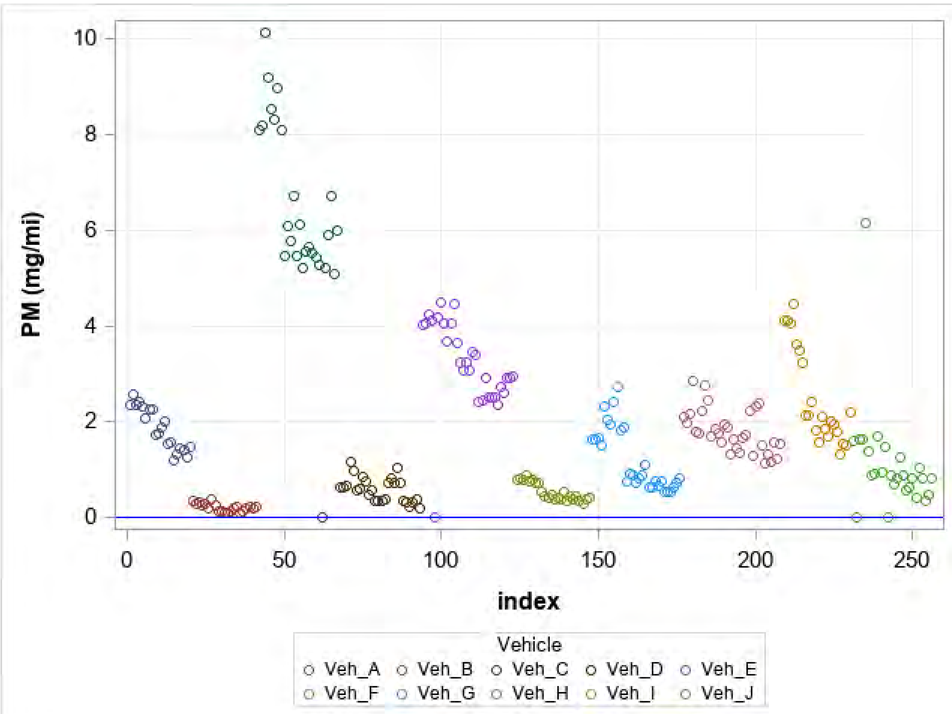

Figure 2.8. FTP PM dataset by vehicle, linear scale.

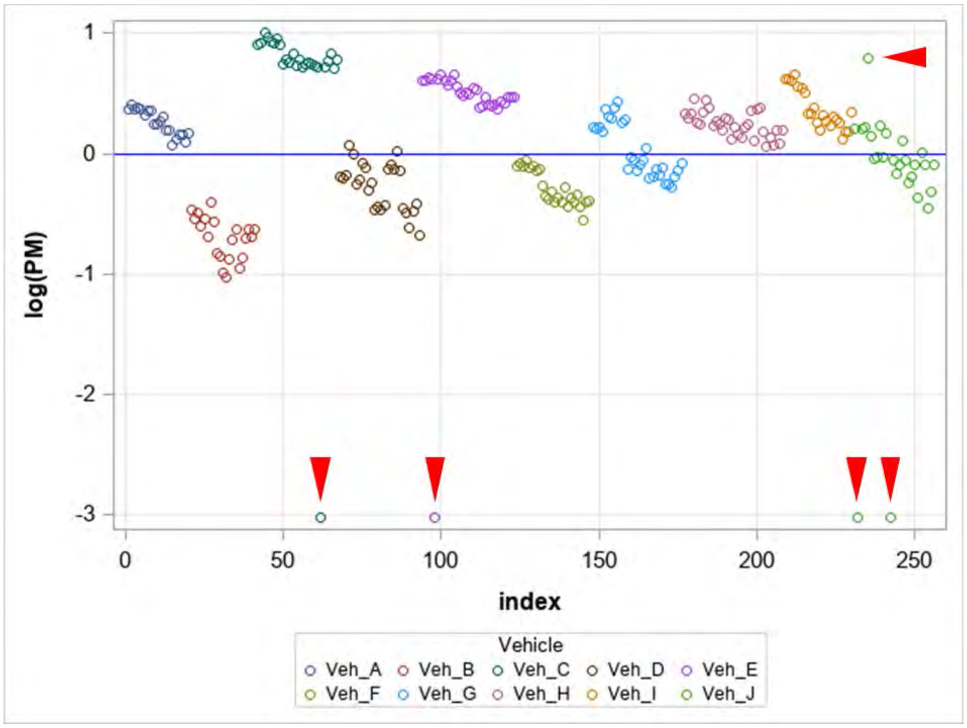

Figure 2.9. FTP PM dataset by vehicle, log scale. Arrows indicate data removed from the analysis.

In Figure 2.9 five points are marked that were removed from the dataset before further analysis, on the basis that they were sufficiently low or high as to indicate a procedural or instrumentation issue with those particular tests. Figure 2.10 plots the remaining data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.11 shows vehicle means by PM Index and indicates that all vehicles had an upward PM trend between the low and high PM Index levels. It is notable that Veh_B, Veh_C, and Veh_E showed an upward trend for Fuel D, despite it having the lowest PMI. Table 2.14 summarizes the number of measurements collected and analyzed for each vehicle.

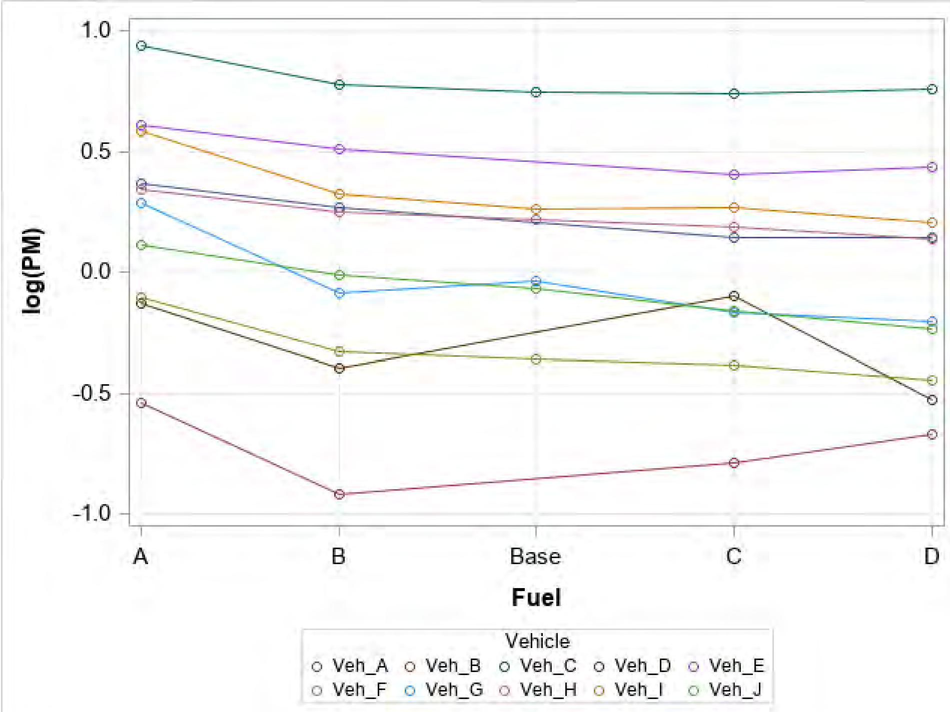

Figure 2.10. FTP PM data as vehicle means by fuel, log scale.

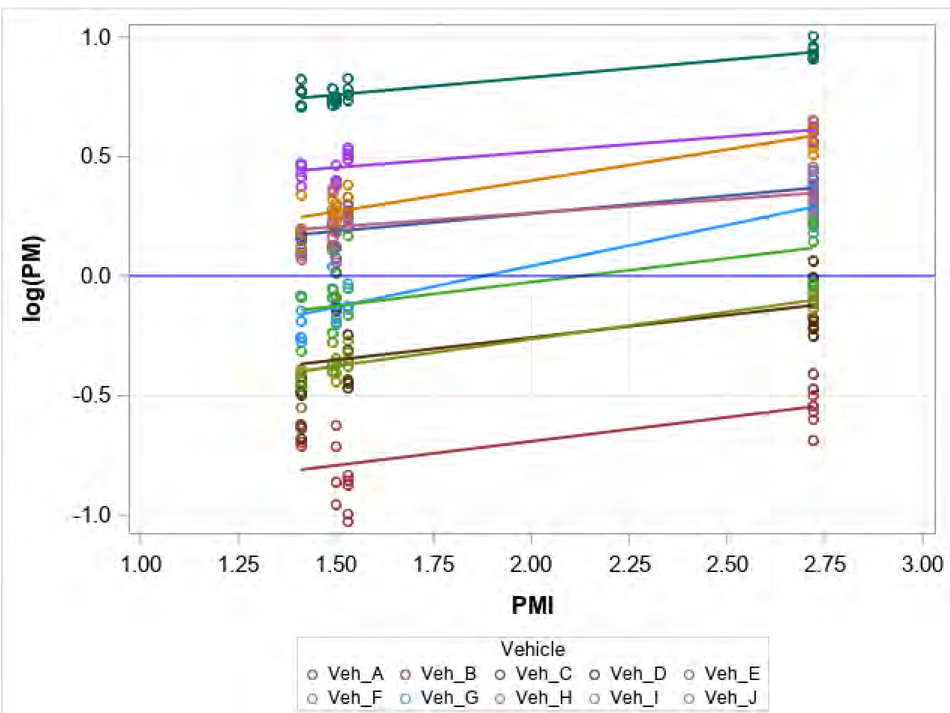

Figure 2.11. FTP PM data as vehicle means by PM Index, log scale.

Table 2.14. Number of PM measurements collected and analyzed in the FTP cycle data analysis.

	Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
Measurements collected	20	21	26	26	30	24	29	32	22	26	256
Measurements removed	0	0	1	0	1	0	0	0	0	3	5
Final dataset	**20**	**21**	**25**	**26**	**29**	**24**	**29**	**32**	**22**	**23**	**251**

Data analysis was performed using the SAS software package (current version). All emissions data were log-transformed before model fitting began, with the exception of CO_2. This is a common practice, as vehicle emissions tend to follow approximately log-normal distributions. In addition, this transformation is a standard approach to normalizing the distributions of residuals and stabilizing their variance across a range of emission levels.[2]

The SAS Mixed procedure was used with the restricted maximum likelihood (REML) method in an initial round of model fitting to examine the behavior of residuals and assess the effect of generating covariance parameters specific to each vehicle. Adding these parameters produced a meaningful improvement in fit, therefore this feature was retained in the final model fitting.

Figure 2.12 indicates conditional studentized residuals are approximately normally distributed with minimal deviation across quantiles. Figure 2.13 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points fall within the acceptable range.

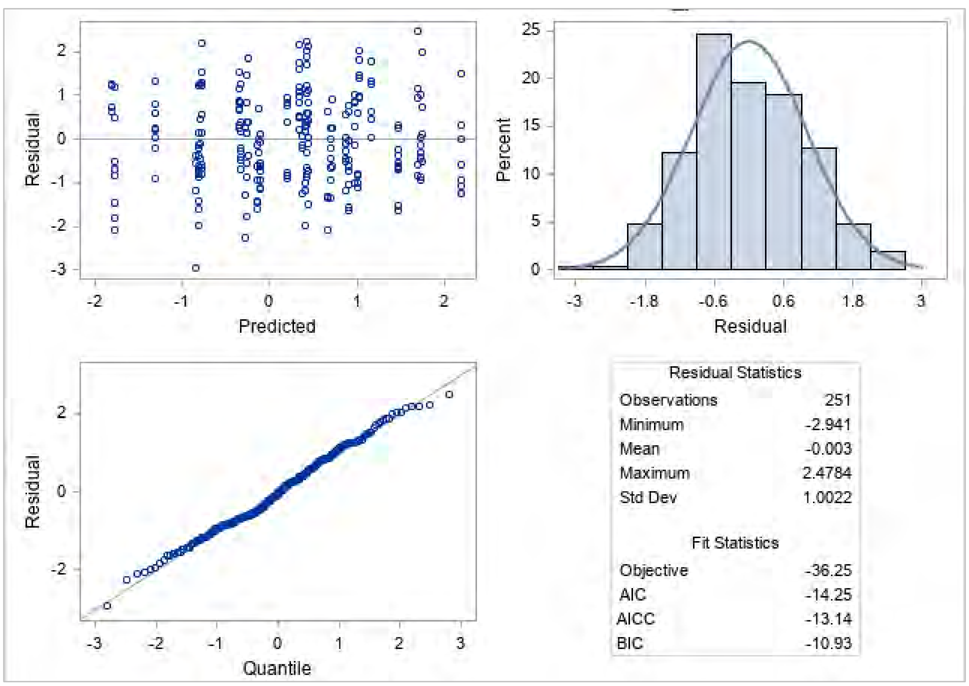

Figure 2.12. Analysis of conditional studentized residuals for FTP cycle PM data.

[2] Additional discussion is available in Section 5.1 of the EPAct study report, EPA-420-R-13-002, April 2013.

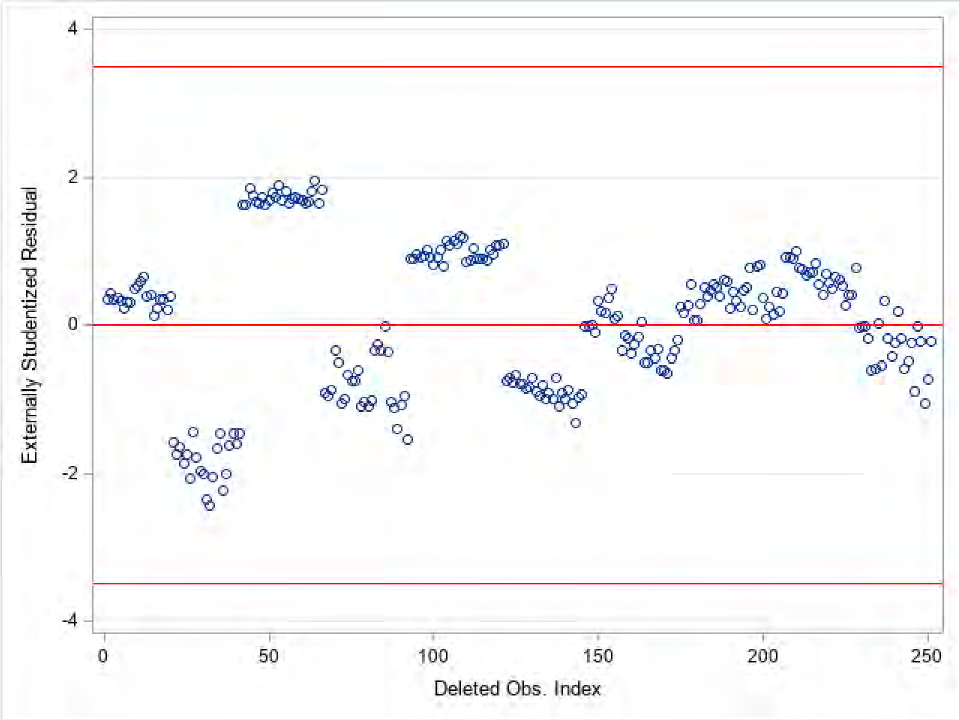

Figure 2.13. Externally studentized residuals for PM FTP cycle data.

Following this initial analysis, the model was refit using the maximum likelihood method to generate the intercept and fixed effect coefficient for the PMI fuel term. The model parameters and related fit statistics are presented in Table 2.15. These results indicate that PMI is a highly significant predictor of PM emissions, and they can be used to compute a relative difference of 1.45 percent in vehicle PM emissions per percent PMI change as the overall study result.

Table 2.15. Fixed effect model parameters for FTP PM.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-0.5117	0.3084	10.2	-1.66	0.1274
PMI	0.3779	0.0176	113	21.48	<.0001

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.16 presents least squares means for fuel pairs.

Table 2.16. Differences in least squares means by fuel for FTP PM.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	0.3224	0.0257	85.6	12.54	<.0001
A	**C**	0.5046	0.0258	84.9	19.59	<.0001
A	**D**	0.4975	0.0253	86.3	19.65	<.0001
A	**Base**	0.4397	0.0370	81.3	11.88	<.0001
B	**C**	0.1822	0.0295	84.3	6.17	<.0001
B	**D**	0.1751	0.0291	85.4	6.01	<.0001
B	**Base**	0.1173	0.0398	93.3	2.95	0.0321
C	**D**	-0.0071	0.0292	84.9	-0.24	0.9992
C	**Base**	-0.0649	0.0399	93.3	-1.63	0.4833
D	**Base**	-0.0578	0.0394	88.7	-1.47	0.5870

Differences should be interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results indicate that Fuel A produced significantly higher PM than the other fuels, and Fuel B produced significantly higher PM than Fuels C, D, and Base. Differences among Fuels C, D, and Base were not significant.

US06 Cycle Results

The presentation of the US06 PM results follows the same outline as for the FTP cycle. Figure 2.14 and Figure 2.15 provide a graphical overview of the measurements collected on the US06 test cycle, grouped by vehicle, on linear and log scales, respectively. The axis label "index" refers to the count of individual observations. For this test cycle, the vehicle means range from under 0.5 mg/mi to about 4 mg/mi, with individual vehicles spanning up to about 5 mg/mi over their fuel and replicate sets.

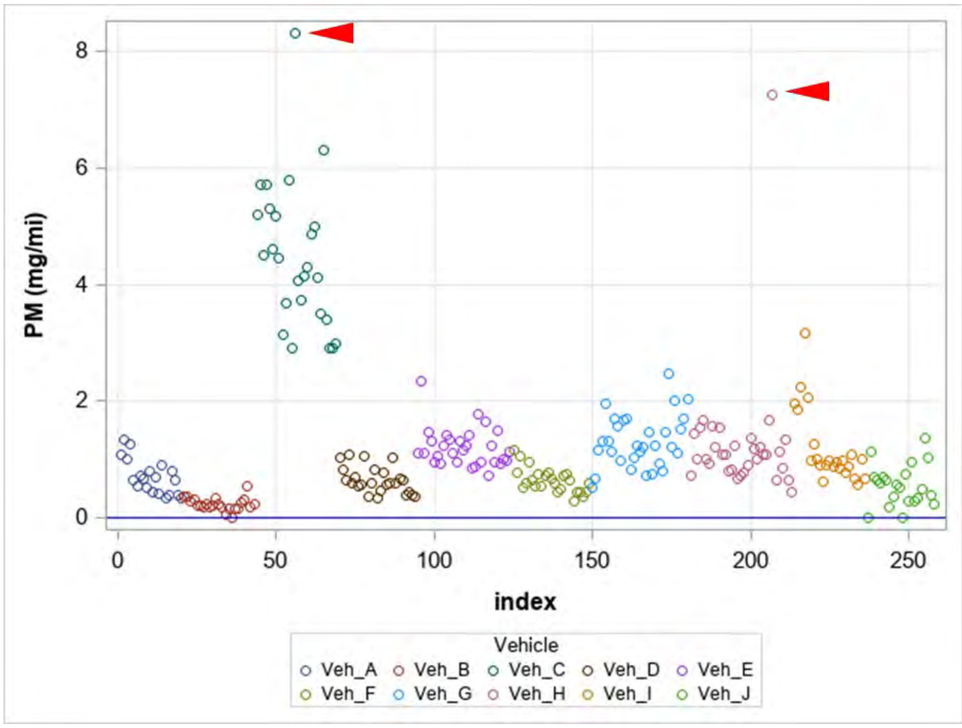

Figure 2.14. US06 PM dataset by vehicle, linear scale. Arrows indicate data removed from the analysis.

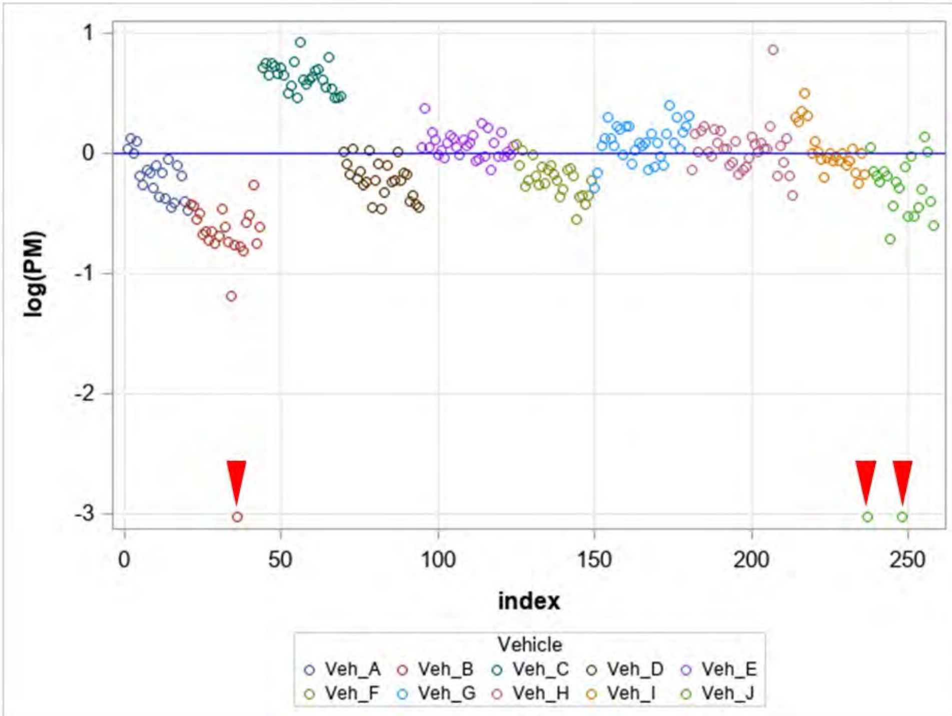

Figure 2.15. US06 PM dataset by vehicle, log scale. Arrows indicate data removed from the analysis.

Across these two plots are marked five points that were considered candidates for removal from the dataset on the basis that they were sufficiently low or high as to indicate a procedural or instrumentation issue with those particular tests. On the log plot, the uppermost point for Veh_C looks plausibly like the upper edge of its typical operation, while on the linear plot it appears to be significantly higher than the other measurements. Review of gaseous data including CO_2 found nothing unusual for that test. However, a plot of MicroSoot Sensor (MSS) results versus PM (Figure 2.16) shows this point (orange triangle) sitting far off the correlation trend observed for this vehicle's other US06 tests. Thus, all five points were removed on the basis of procedural or analytical problems.

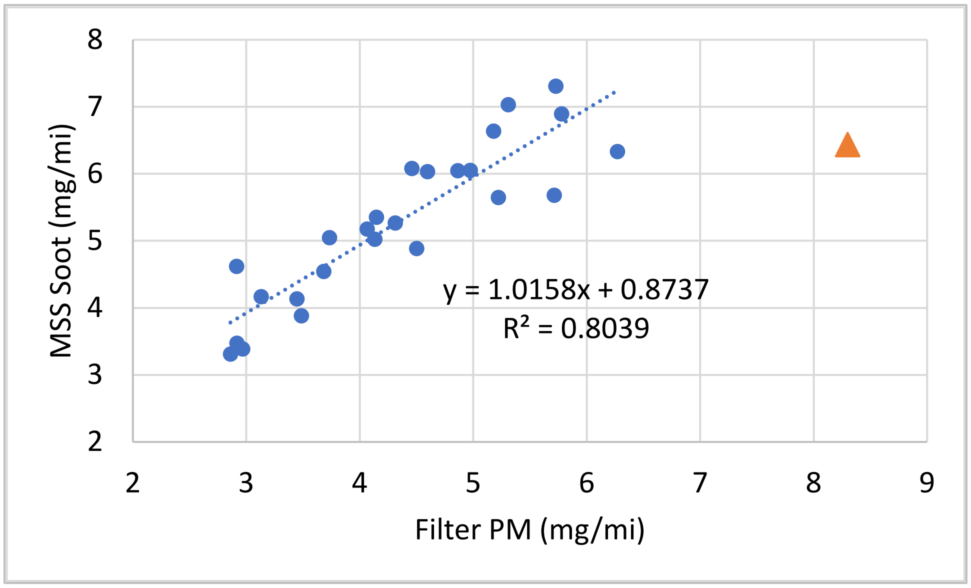

Figure 2.16. Comparison of MicroSoot Sensor and PM data for Veh_C. Triangular point indicates a measurement far away from the correlation trend.

Figure 2.17 plots the remaining data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.18 shows vehicle means by PM Index, where most vehicles indicate an upward PM trend between the low and high PM Index levels. However, three vehicles (Veh_B, Veh_G, and Veh_J) produced PM levels from Fuel D that were equal to or greater than on Fuel A, despite Fuel D having the lowest PMI. Table 2.17 summarizes the number of measurements collected and analyzed for each vehicle.

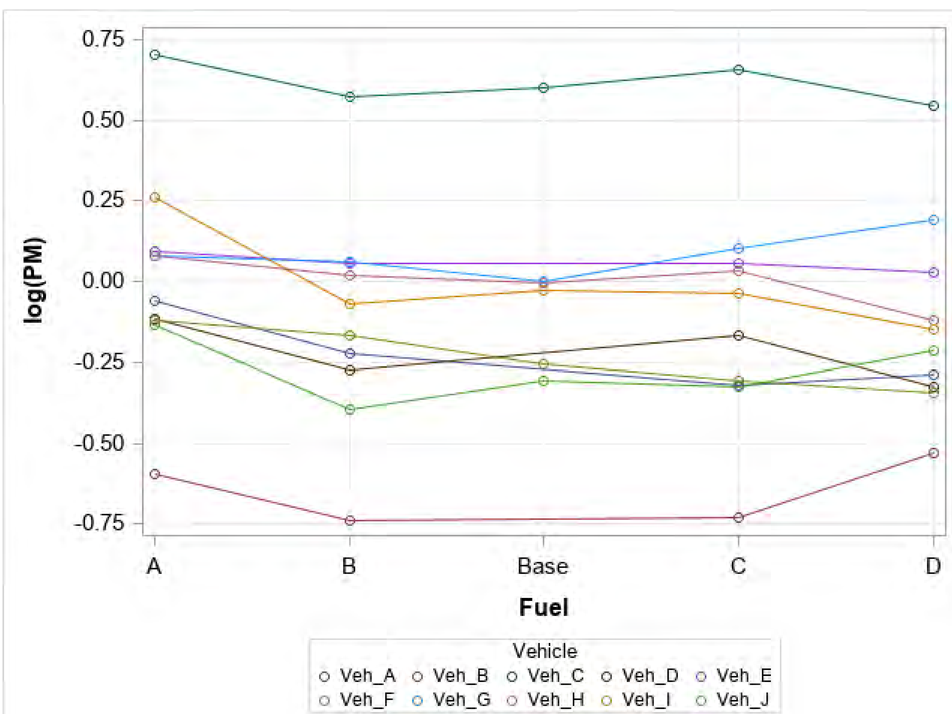

Figure 2.17. US06 PM data as vehicle means by fuel, log scale.

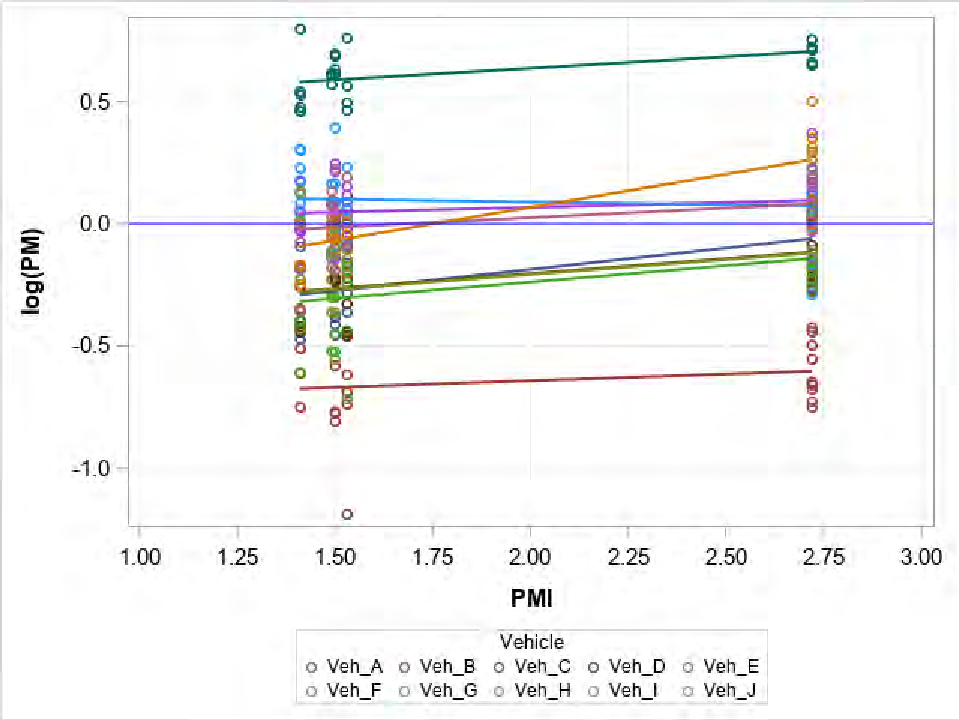

Figure 2.18. US06 PM data as vehicle means by PM Index, log scale.

Table 2.17. Number of PM measurements collected and analyzed in the US06 cycle model fitting.

	Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
Measurements collected	20	23	26	25	30	25	31	33	23	22	258
Measurements removed	0	1	1	0	0	0	0	1	0	2	5
Final dataset	**20**	**22**	**25**	**25**	**30**	**25**	**31**	**32**	**23**	**20**	**253**

Data analysis and model fitting proceeded in the same manner as for the FTP cycle as described above, including log transformation of the data and generation of covariance parameter estimates on a per-vehicle basis. Figure 2.19 indicates conditional studentized residuals are approximately normally distributed with minimal deviation across quantiles. Figure 2.20 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points fall within the acceptable range.

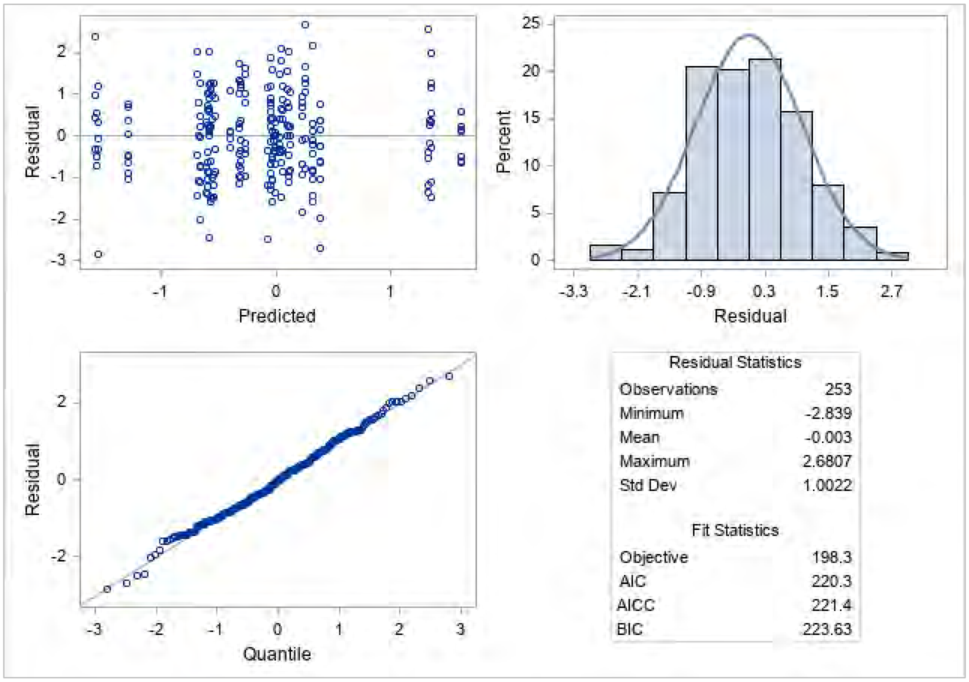

Figure 2.19. Analysis of conditional studentized residuals for US06 cycle PM data.

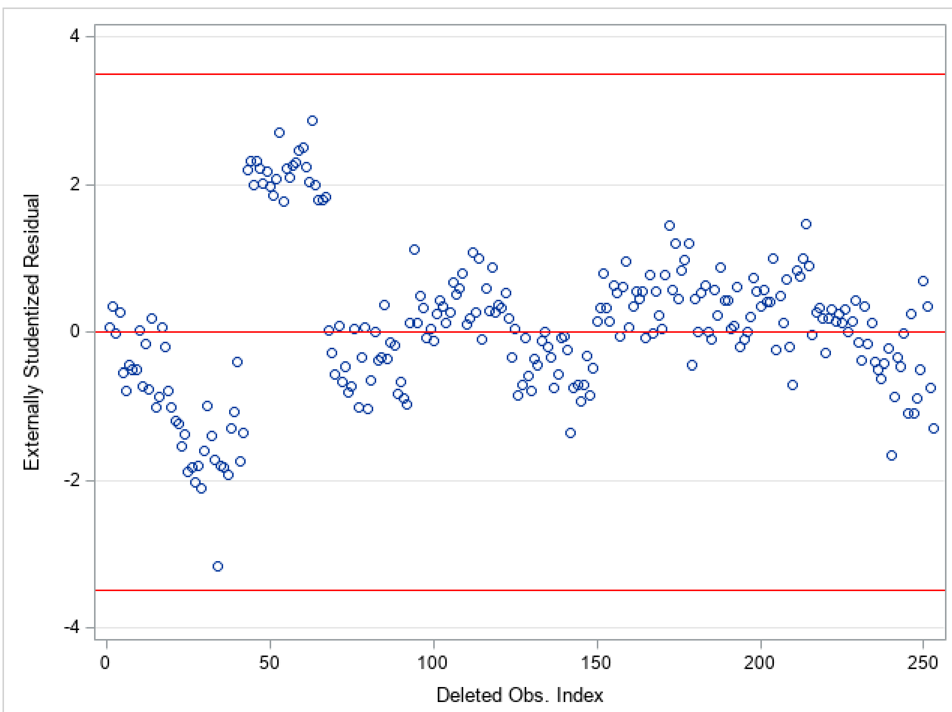

Figure 2.20. Externally studentized residuals for US06 cycle PM data.

The intercept and fixed effect coefficient for the PMI fuel term are presented in Table 2.18. These results indicate that PMI is a highly significant predictor of PM emissions, and can be used to compute a relative difference of 1.0 percent in vehicle PM emissions per percent PMI change as the overall study result for the US06 test cycle.

Table 2.18. Fixed effect model parameters for US06 PM.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-0.5799	0.2373	11.5	-2.44	0.0317
PMI	0.2208	0.0346	191	6.38	<.0001

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.19 presents least squares means for fuel pairs.

Table 2.19. Differences in least squares means by fuel for US06 PM.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	0.2583	0.0584	189	4.42	0.0002
A	**C**	0.2177	0.0596	186	3.65	0.0031
A	**D**	0.3374	0.0569	169	5.92	<.0001
A	**Base**	0.2618	0.0731	126	3.58	0.0043
B	**C**	-0.0406	0.0680	189	-0.60	0.9753
B	**D**	0.0791	0.0656	176	1.21	0.7478
B	**Base**	0.0035	0.0801	142	0.04	1.0000
C	**D**	0.1197	0.0667	174	1.80	0.3794
C	**Base**	0.0442	0.0809	143	0.55	0.9823
D	**Base**	-0.0756	0.0790	134	-0.96	0.8742

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results indicate that Fuel A produced significantly higher PM than the other fuels, but that differences between other fuels were not significant.

2.4.2. NOx Emissions

FTP Cycle Results

Figure 2.21 and Figure 2.22 provide a graphical overview of NOx measurements collected on the FTP cycle, grouped by vehicle, on linear and log scales, respectively. The axis label “index” refers to the count of individual observations. Vehicle means range from about 2 mg/mi to about 30 mg/mi, with individual vehicle ranges smaller from a few mg/mi to over 30 mg/mi. Veh_C shows especially high variability over its replicates.

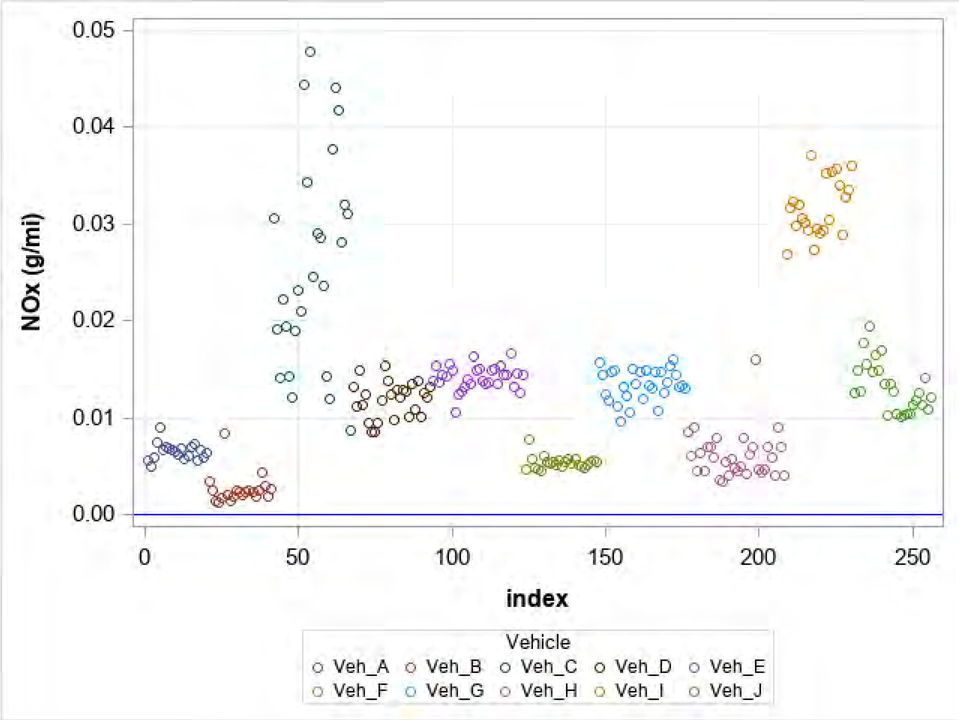

Figure 2.21. FTP NOx dataset by vehicle, linear scale.

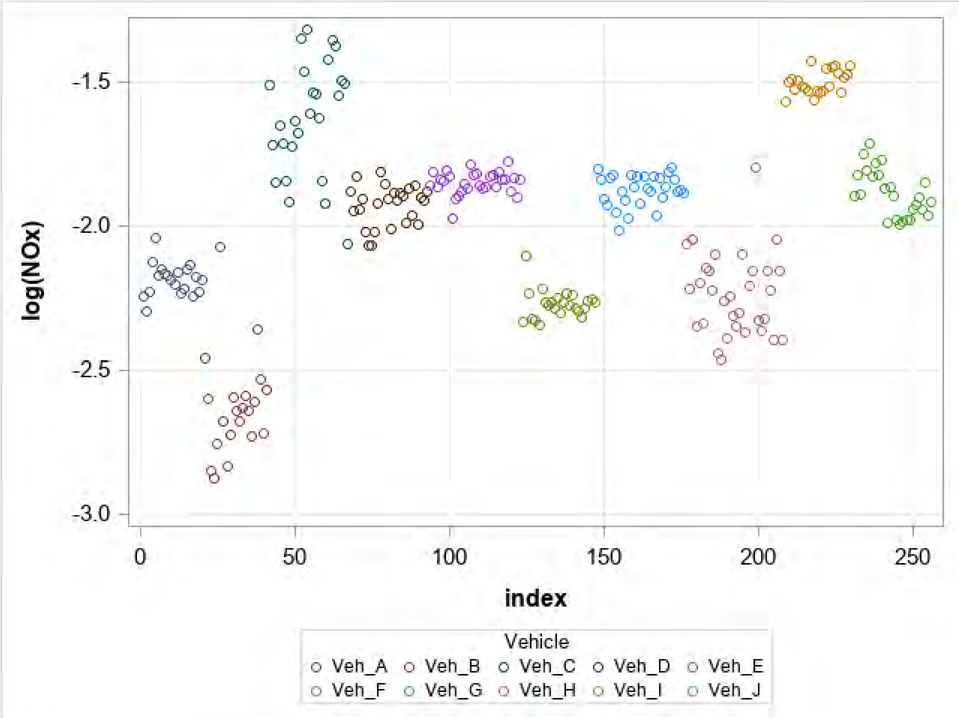

Figure 2.22. FTP NOx dataset by vehicle, log scale.

Figure 2.23 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.24 shows vehicle means by PM Index, where some vehicles have increasing NOx trends with PM Index, and others flat or decreasing. Table 2.20 summarizes the number of measurements collected and analyzed for each vehicle.

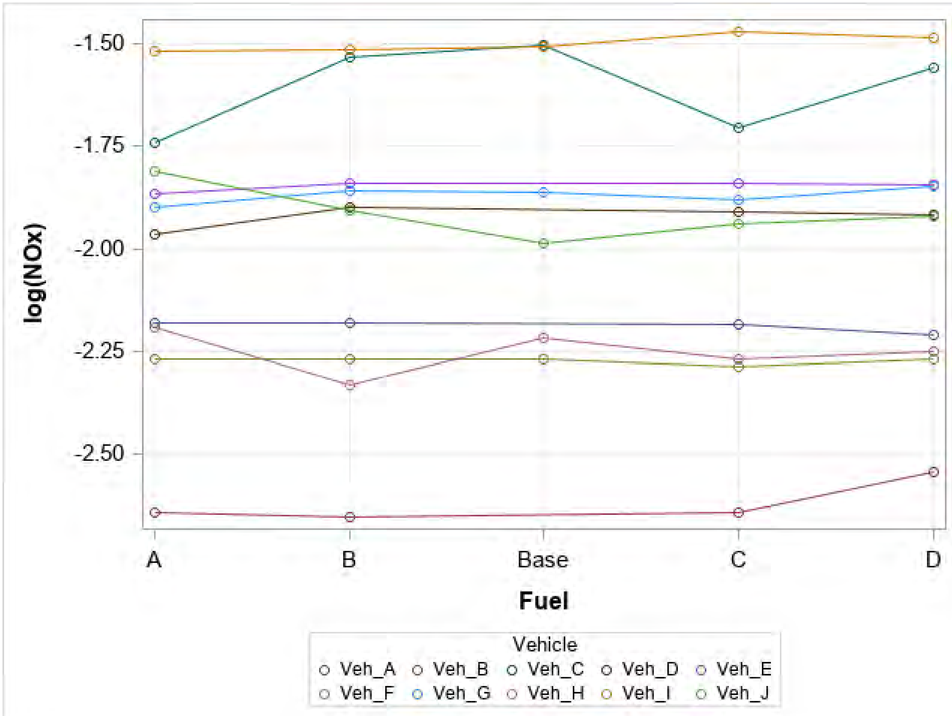

Figure 2.23. FTP NOx data as vehicle means by fuel, log scale.

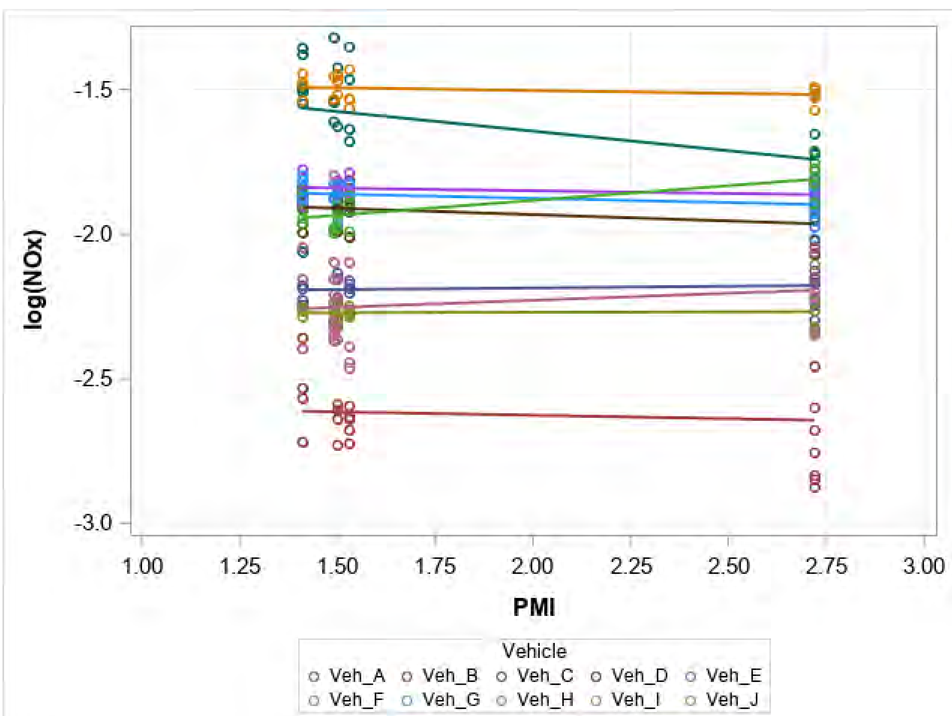

Figure 2.24. FTP NOx data as vehicle means by PM Index, log scale.

Table 2.20. Number of NOx measurements collected and analyzed in the FTP cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	21	26	26	30	24	29	32	22	26	256

Data analysis was performed using the SAS software package (current version). All NOx emissions data were log-transformed before model fitting began. This is a common practice, as vehicle emissions tend to follow approximately log-normal distributions. In addition, this transformation is a standard approach to normalizing the distributions of residuals and stabilizing their variance across a range of emission levels.[3]

The SAS Mixed procedure was used with the restricted maximum likelihood (REML) method in an initial round of model fitting to examine the behavior of residuals and assess the effect of generating covariance parameters specific to each vehicle. Figure 2.25 indicates conditional studentized residuals are approximately normally distributed with some minor deviation toward the upper tail. Figure 2.26 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for "outlier points". Results indicate all points fall within the acceptable range.

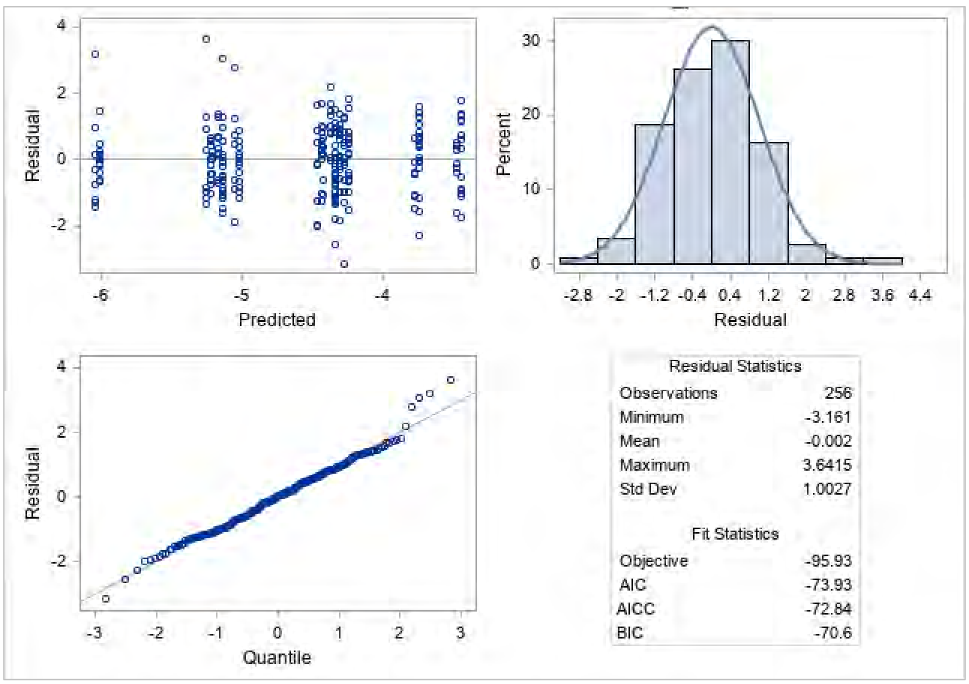

Figure 2.25. Analysis of conditional studentized residuals for FTP cycle NOx data.

[3] Additional discussion is available in Section 5.1 of the EPAct study report, EPA-420-R-13-002, April 2013.

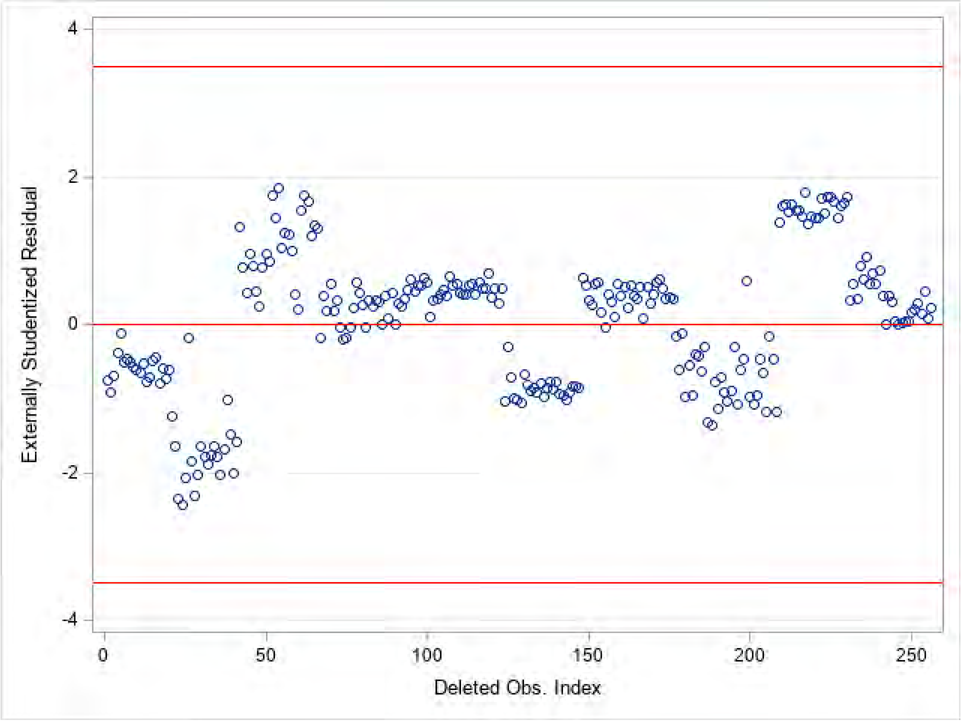

Figure 2.26. Externally studentized residuals for FTP cycle NOx data.

Following this initial analysis, the model was refit using the maximum likelihood method to generate the intercept and fixed effect coefficient for the PMI fuel term. The model parameters and related fit statistics are presented in Table 2.21. These results indicate that PMI is not a significant predictor of NOx emissions in the FTP.

Table 2.21. PMI model parameters for FTP NOx.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-4.5537	0.2312	10.2	-19.69	<.0001
PMI	-0.02484	0.01514	145	-1.64	0.103

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.22 presents differences of least squares means for fuel pairs.

Table 2.22. Differences in least squares means by fuel for FTP NOx.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	-0.0287	0.0259	140	-1.11	0.8029
A	**C**	-0.0322	0.0258	139	-1.25	0.7233
A	**D**	-0.0378	0.0255	143	-1.48	0.5745
A	**Base**	-0.0076	0.0367	98.5	-0.21	0.9996
B	**C**	-0.0036	0.0298	138	-0.12	1.0000
B	**D**	-0.0091	0.0295	141	-0.31	0.9980
B	**Base**	0.0210	0.0397	109	0.53	0.9841
C	**D**	-0.0056	0.0295	140	-0.19	0.9997
C	**Base**	0.0246	0.0396	108	0.62	0.9714
D	**Base**	0.0302	0.0394	109	0.77	0.9397

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results show no significant differences between any fuel pairs.

US06 Cycle Data

The presentation of the US06 NOx results follows the same outline as for the FTP cycle. Figure 2.27 and Figure 2.28 provide a graphical overview of the measurements collected on the US06 test cycle, grouped by vehicle, on linear and log scales, respectively. The axis label “index” refers to the count of individual observations. For this test cycle, vehicle means range from about 3 mg/mi to about 32 mg/mi, with individual vehicle ranges smaller spanning up to about 15 mg/mi.

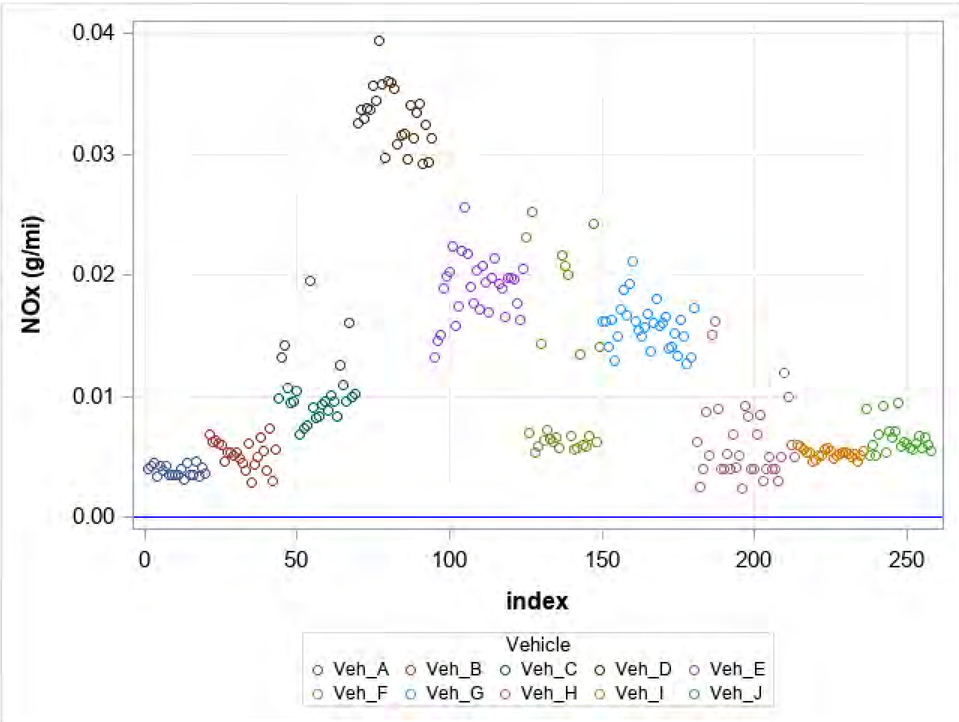

Figure 2.27. US06 NOx dataset by vehicle, linear scale.

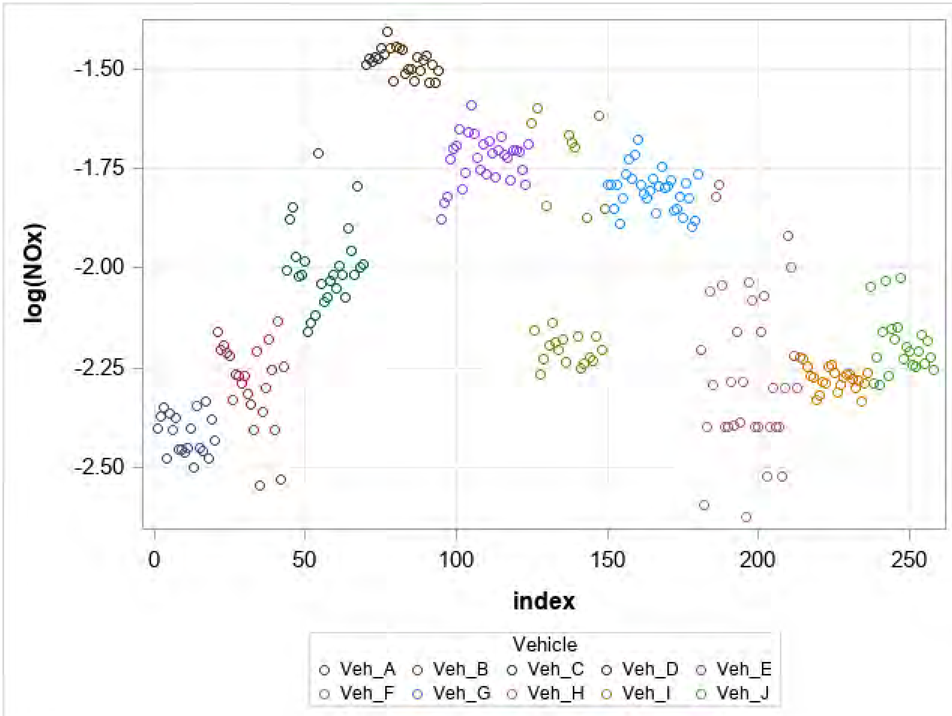

Figure 2.28. US06 NOx dataset by vehicle, log scale.

Figure 2.29 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.30 presents vehicle means by PM Index. Similar to the FTP cycle, some vehicles have increasing NOx trends with increasing PM Index, while others are flat or slightly decreasing. Table 2.23 summarizes the number of measurements collected and analyzed for each vehicle.

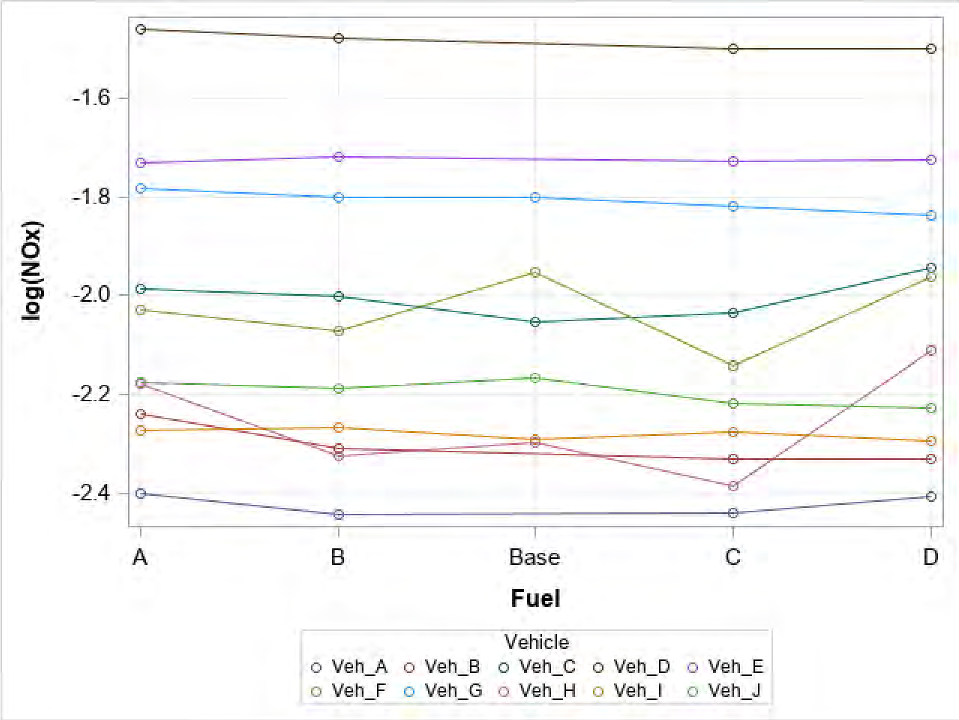

Figure 2.29. US06 NOx data as vehicle means by fuel, log scale.

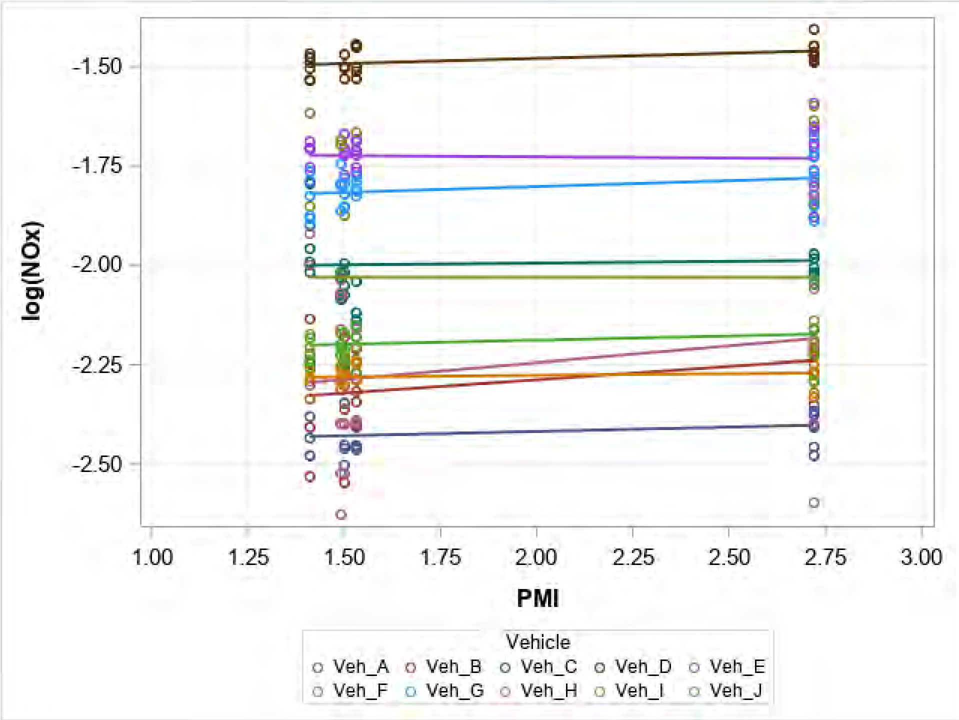

Figure 2.30. US06 NOx data as vehicle means by PM Index, log scale.

Table 2.23. Number of NOx measurements collected and analyzed in the US06 cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	23	26	25	30	25	31	33	23	22	258

Data analysis and model fitting proceeded in the same manner as for the FTP cycle as described above, including log transformation of the data and generation of covariance parameter estimates on a per-vehicle basis. Figure 2.31 indicates conditional studentized residuals are normally distributed with minimal deviation across quantiles. Figure 2.32 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for "outlier points". Results indicate all points are well within the acceptable range.

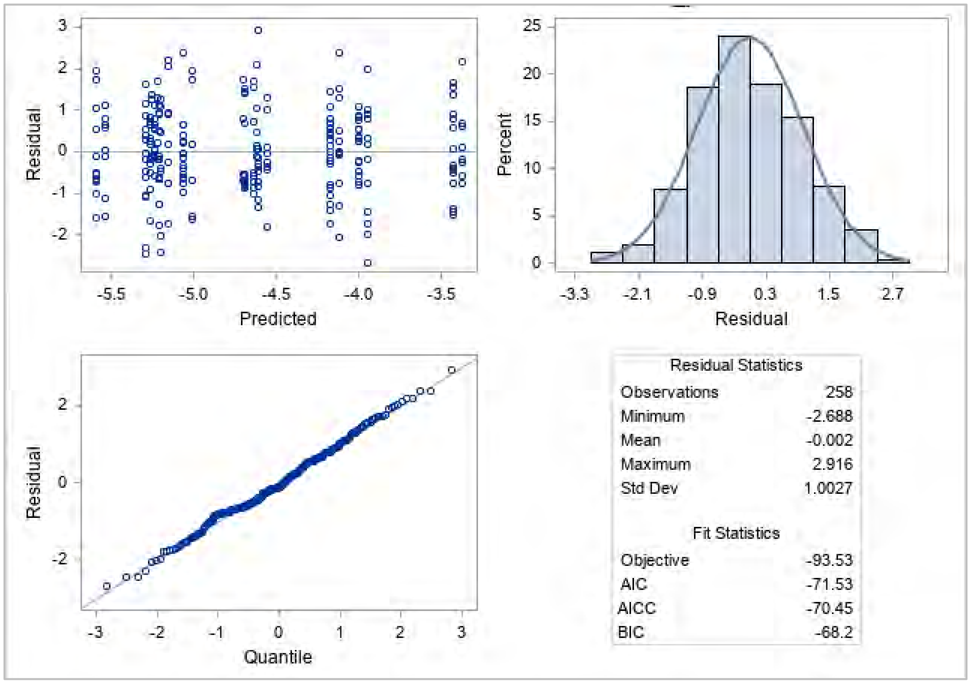

Figure 2.31. Analysis of conditional studentized residuals for US06 cycle NOx data.

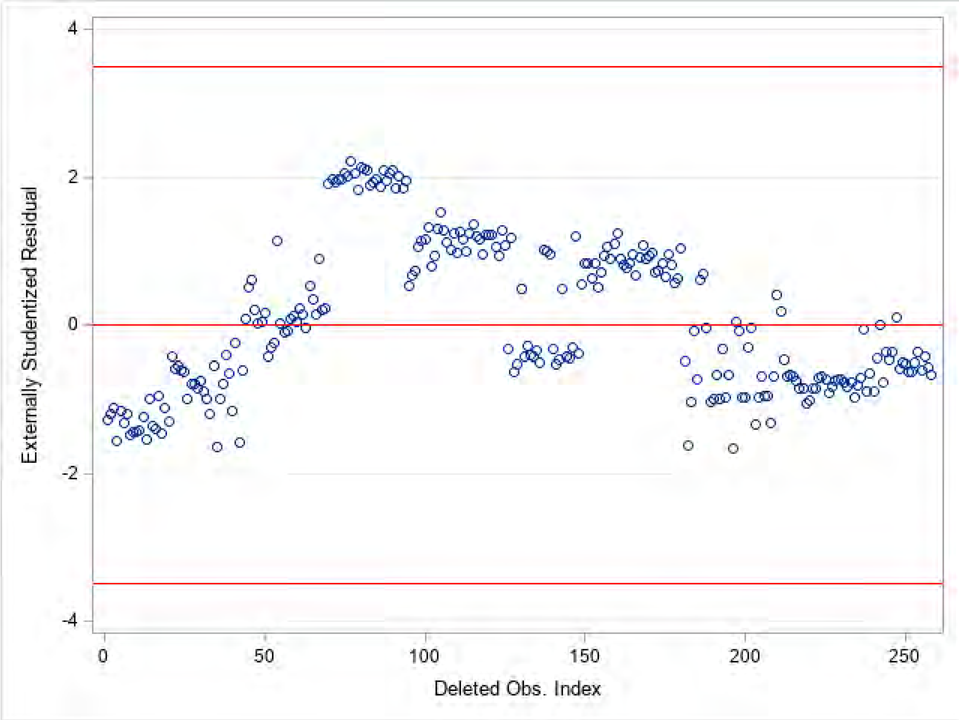

Figure 2.32. Externally studentized residuals for US06 cycle NOx data.

The solution for fixed effects for the PMI fuel parameter model is presented in Table 2.24. These results indicate that PMI is a statistically significant predictor of NOx emissions. These results can be used to compute a relative difference of 0.25 percent in vehicle NOx emissions per percent PMI change as the overall study result for the US06 test cycle.

Table 2.24. Fixed effect model parameters for US06 NOx.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-4.8007	0.2084	10.4	-23.03	<.0001
PMI	0.0452	0.01353	112	3.34	0.0011

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.25 presents differences of least squares means for fuel pairs.

Table 2.25. Differences in least squares means by fuel for US06 NOx.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	-0.0287	0.0259	140	-1.11	0.5519
A	**C**	-0.0322	0.0258	139	-1.25	0.0338
A	**D**	-0.0378	0.0255	143	-1.48	0.0225
A	**Base**	-0.0076	0.0367	98.5	-0.21	0.5576
B	**C**	-0.0036	0.0298	138	-0.12	0.6996
B	**D**	-0.0091	0.0295	141	-0.31	0.6527
B	**Base**	0.0210	0.0397	109	0.53	0.9873
C	**D**	-0.0056	0.0295	140	-0.19	1
C	**Base**	0.0246	0.0396	108	0.62	0.9938
D	**Base**	0.0302	0.0394	109	0.77	0.9922

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results show significant differences between fuel pairs A-C and A-D.

2.4.3. NMOG Emissions

FTP Cycle Data

Figure 2.33 and Figure 2.34 provide a graphical overview of NMOG measurements collected on the FTP cycle, grouped by vehicle, on linear and log scales, respectively. The axis label "index" refers to the count of individual observations. Vehicle means cover a wide range, from about 1 mg/mi to about 45 mg/mi, with individual vehicle ranges around 1 mg/mi to over 20 mg/mi.

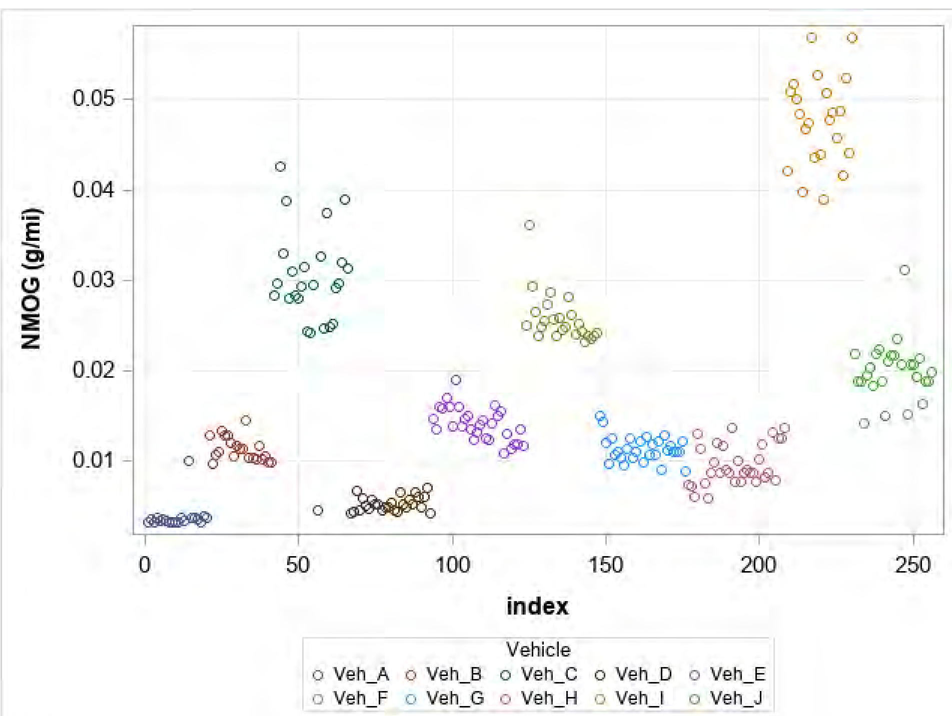

Figure 2.33. FTP NMOG dataset by vehicle, linear scale.

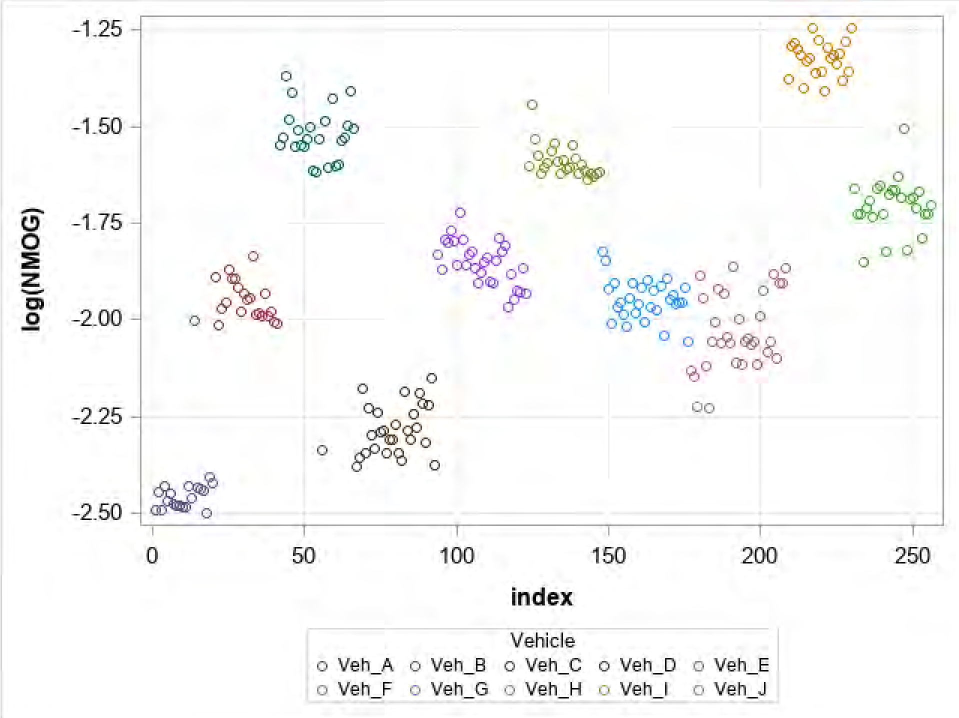

Figure 2.34. FTP NMOG dataset by vehicle, log scale.

Figure 2.35 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.36 shows vehicle means by PM Index, where some vehicles have increasing NMOG trends with PM Index, and others flat or decreasing. Table 2.26 summarizes the number of measurements collected and analyzed for each vehicle.

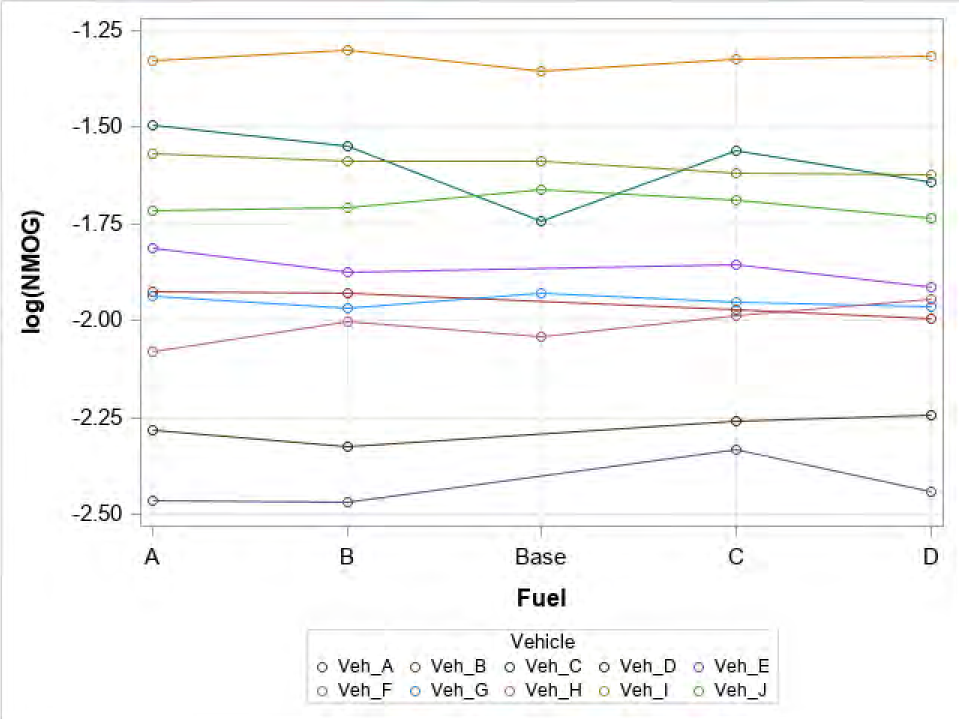

Figure 2.35. FTP NMOG data as vehicle means by fuel, log scale.

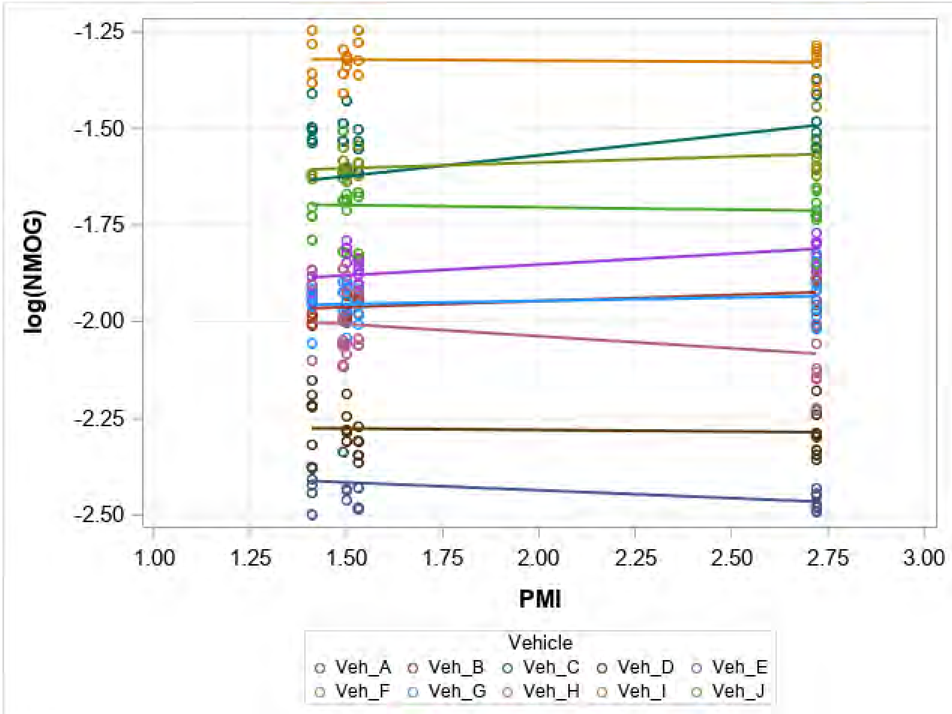

Figure 2.36. FTP NMOG data as vehicle means by PM Index, log scale.

Table 2.26. Number of NMOG measurements collected and analyzed in the FTP cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	21	26	26	30	24	29	32	22	26	256

Data analysis was performed using the SAS software package (current version). All NMOG emissions data were log-transformed before model fitting began. This is a common practice, as vehicle emissions tend to follow approximately log-normal distributions. In addition, this transformation is a standard approach to normalizing the distributions of residuals and stabilizing their variance across a range of emission levels.[4]

The SAS Mixed procedure was used with the restricted maximum likelihood (REML) method in an initial round of model fitting to examine the behavior of residuals and assess the effect of generating covariance parameters specific to each vehicle. Figure 2.37 indicates conditional studentized residuals are approximately normally distributed with some minor deviation toward the tails. Figure 2.38 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for "outlier points". Results indicate all points are well within the acceptable range.

[4] Additional discussion is available in Section 5.1 of the EPAct study report, EPA-420-R-13-002, April 2013.

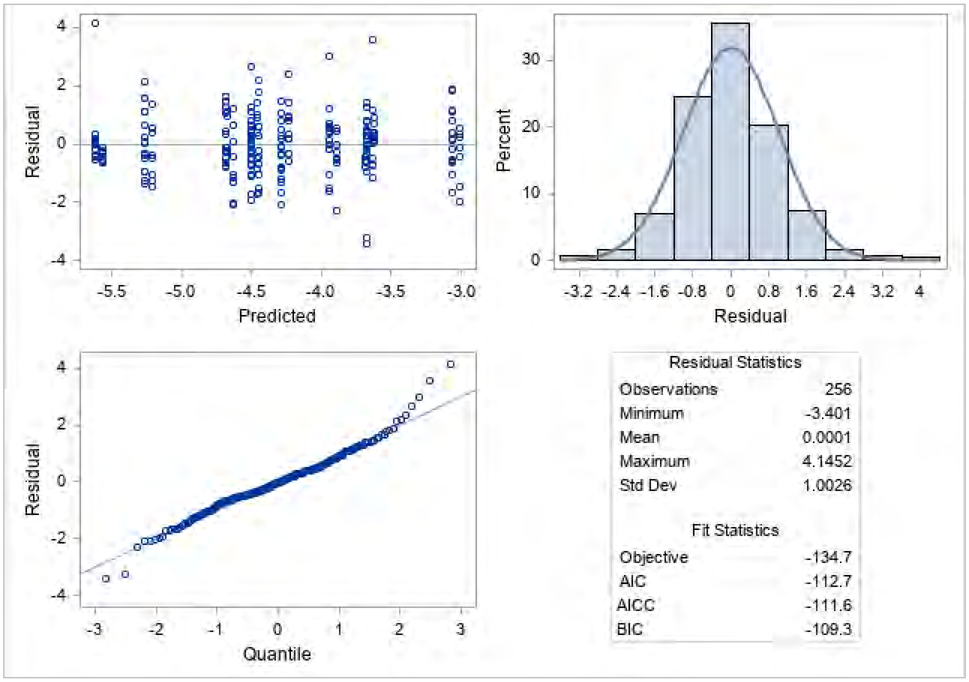

Figure 2.37. Analysis of conditional studentized residuals for FTP cycle NMOG data.

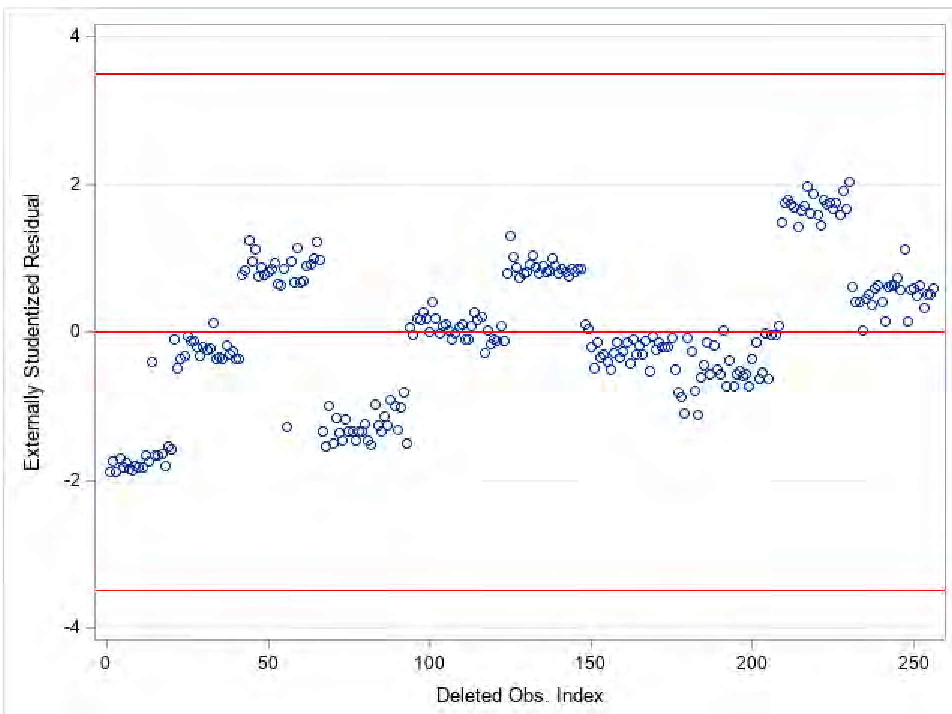

Figure 2.38. Externally studentized residuals for FTP cycle NMOG data.

Following this initial analysis, the model was refit using the maximum likelihood method to generate the intercept and fixed effect coefficient for the PMI fuel term. The model parameters and related fit statistics are presented in Table 2.27. These results indicate that PMI is a statistically significant predictor of NMOG emissions, but with a relatively small effect at 0.22 percent NMOG emissions per percent PMI.

Table 2.27. PMI model parameters for FTP NMOG.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-4.3822	0.2332	10.3	-18.8	<.0001
PMI	0.03994	0.01523	171	2.62	0.0095

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.28 presents differences of least squares means for fuel pairs.

Table 2.28. Differences in least squares means by fuel for FTP NMOG.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	0.038	0.02568	160	1.48	0.577
A	**C**	0.04129	0.0259	162	1.59	0.5034
A	**D**	0.08336	0.02552	165	3.27	0.0114
A	**Base**	0.02893	0.0341	102	0.85	0.9147
B	**C**	0.00329	0.02974	160	0.11	1
B	**D**	0.04535	0.02942	163	1.54	0.5371
B	**Base**	-0.0091	0.03725	116	-0.24	0.9992
C	**D**	0.04207	0.02962	164	1.42	0.6154
C	**Base**	-0.0124	0.03732	115	-0.33	0.9974
D	**Base**	-0.0544	0.03708	115	-1.47	0.5852

Differences in Table 2.28 are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. The results show significant differences between Fuel A and Fuel D.

US06 Cycle Data

Figure 2.39 provides an initial review of NMOG measurements collected on the US06 test cycle, grouped by vehicle. The axis label "index" refers to the count of individual observations. The red arrows near the bottom of the figure highlight several tests that produced zero-value NMOG results, indicating emissions were below the quantitation limit of the measurement equipment. Given that the majority of measurements from Veh_H were zeros, a decision was made to remove this vehicle's US06 NMOG emissions from subsequent analysis. In addition, one highlighted point from Veh_G was also removed. The remaining data is shown in Figure 2.40 and Figure 2.41, where the vehicle means fall between 2-20 mg/mi, except for one vehicle that had a mean around 50 mg/mi and a relatively large span.

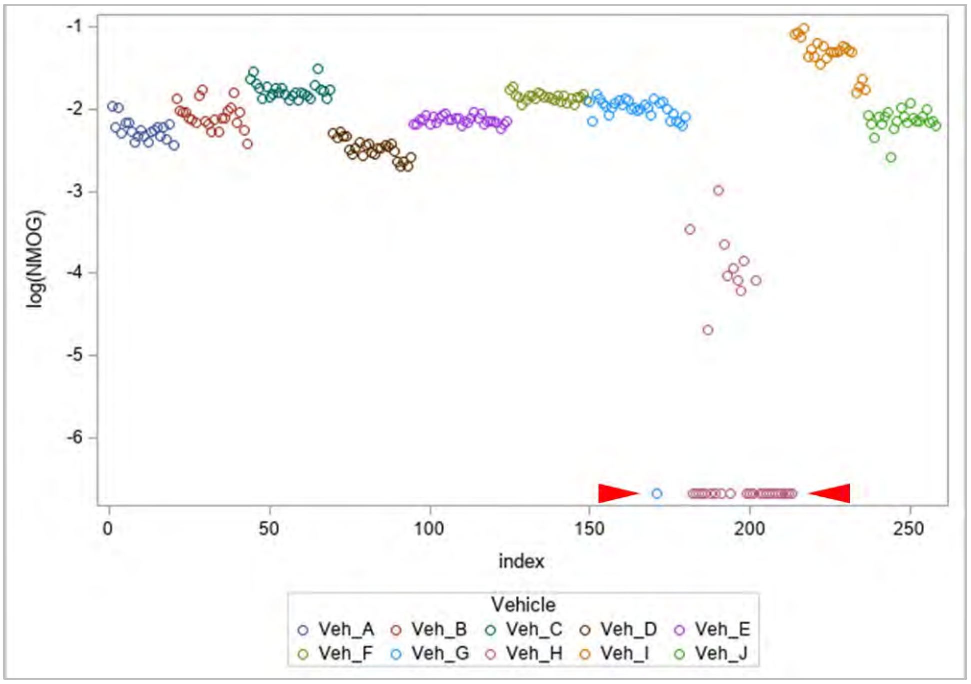

Figure 2.39. US06 NMOG dataset by vehicle, log scale. Red arrows indicate zero-value measurements.

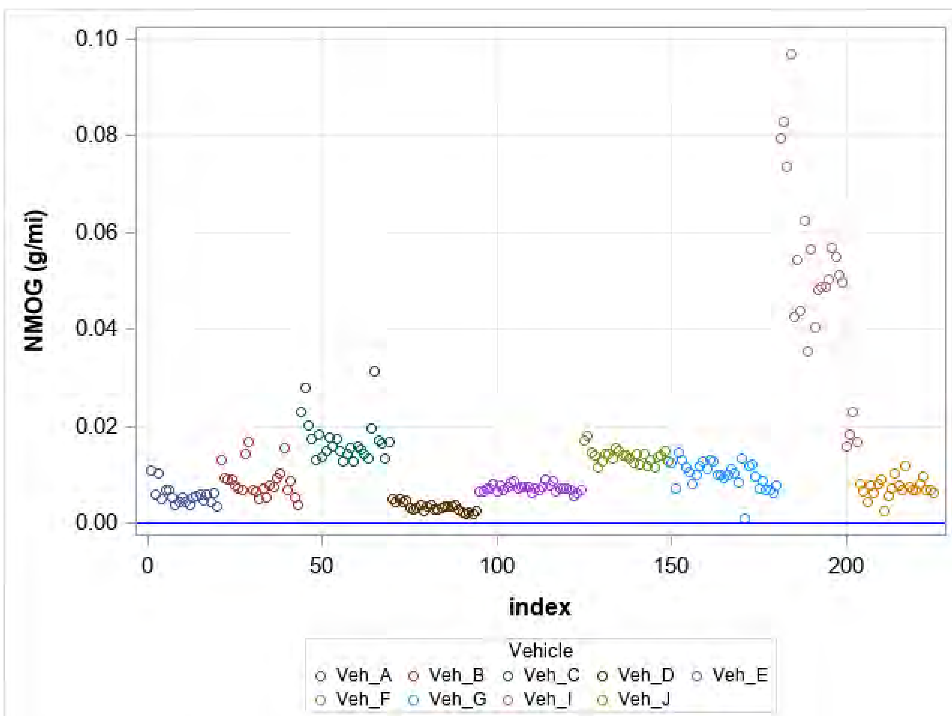

Figure 2.40. US06 NMOG dataset used in the analysis, linear scale.

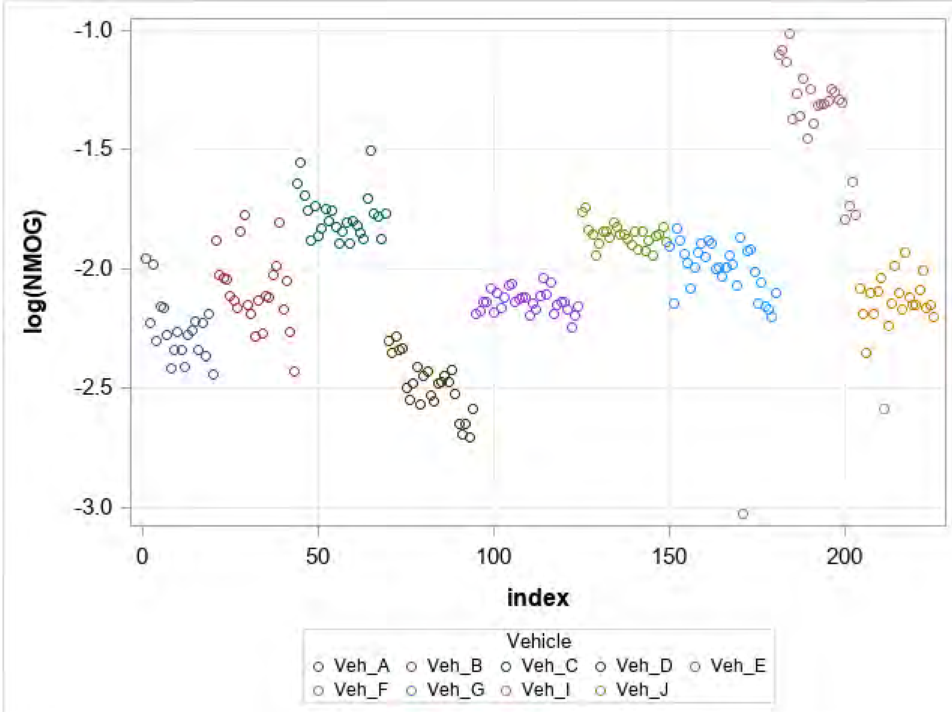

Figure 2.41. US06 NMOG dataset used in the analysis, log scale.

Figure 2.42 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.43 presents vehicle means by PM Index. Similar to the FTP cycle, some vehicles have increasing NMOG trends with increasing PM Index, while others are flat or slightly decreasing. Table 2.29 summarizes the number of measurements collected and analyzed for each vehicle.

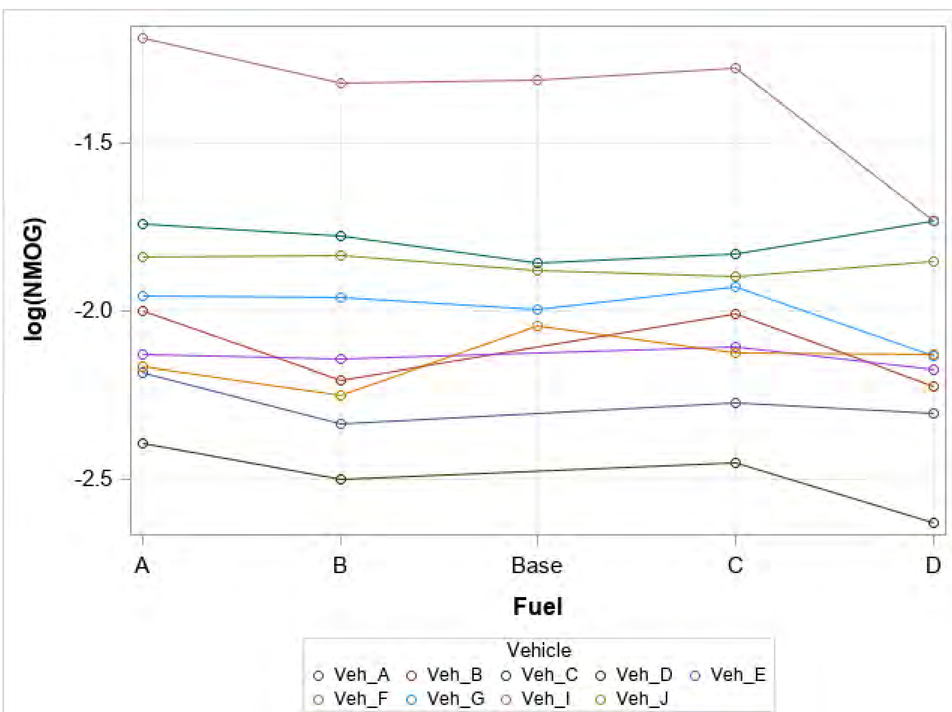

Figure 2.42. US06 NMOG data as vehicle means by fuel, log scale.

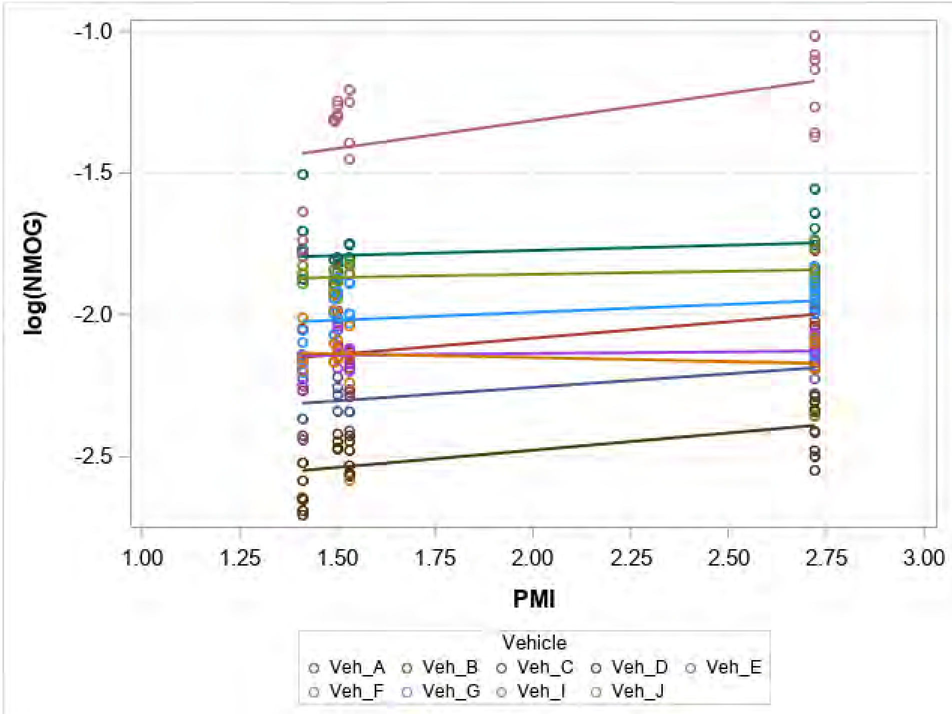

Figure 2.43. US06 NMOG data as vehicle means by PM Index, log scale.

Table 2.29. Number of NMOG measurements collected and analyzed in the US06 cycle model fitting.

	Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
Measurements collected	20	23	26	25	30	25	31	33	23	22	258
Measurements removed	0	0	0	0	0	0	1	33	0	0	34
Used in analysis	**20**	**23**	**26**	**25**	**30**	**25**	**30**	**0**	**23**	**22**	**224**

Data analysis and model fitting proceeded in the same manner as for the FTP cycle as described above, including log transformation of the data and generation of covariance parameter estimates on a per-vehicle basis. Figure 2.44 indicates conditional studentized residuals are normally distributed with minimal deviation across quantiles. Figure 2.45 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points fall within the acceptable range.

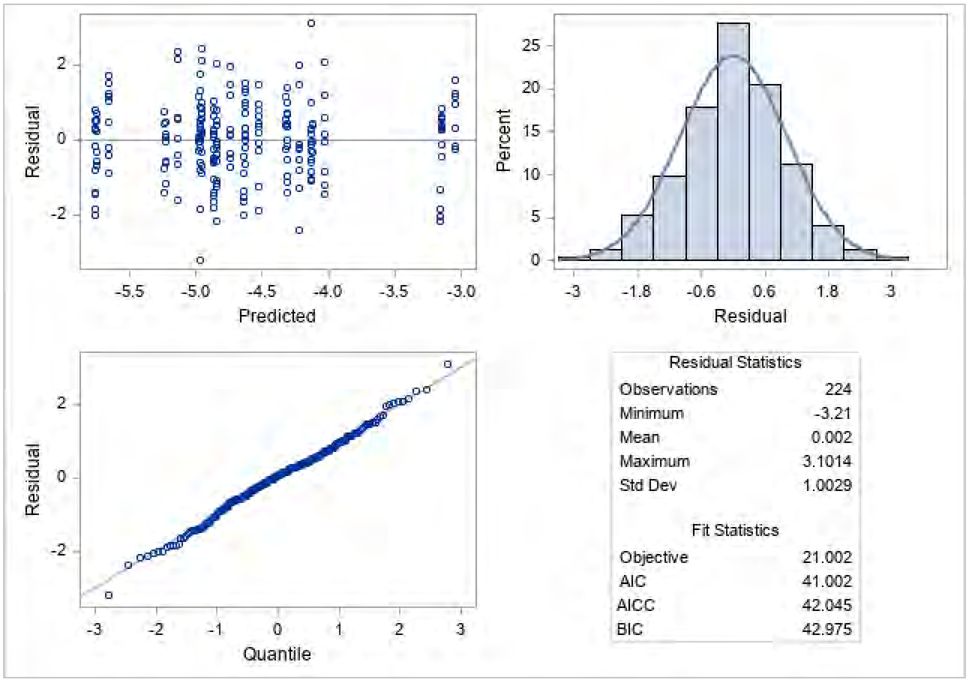

Figure 2.44. Analysis of conditional studentized residuals for US06 cycle NMOG data.

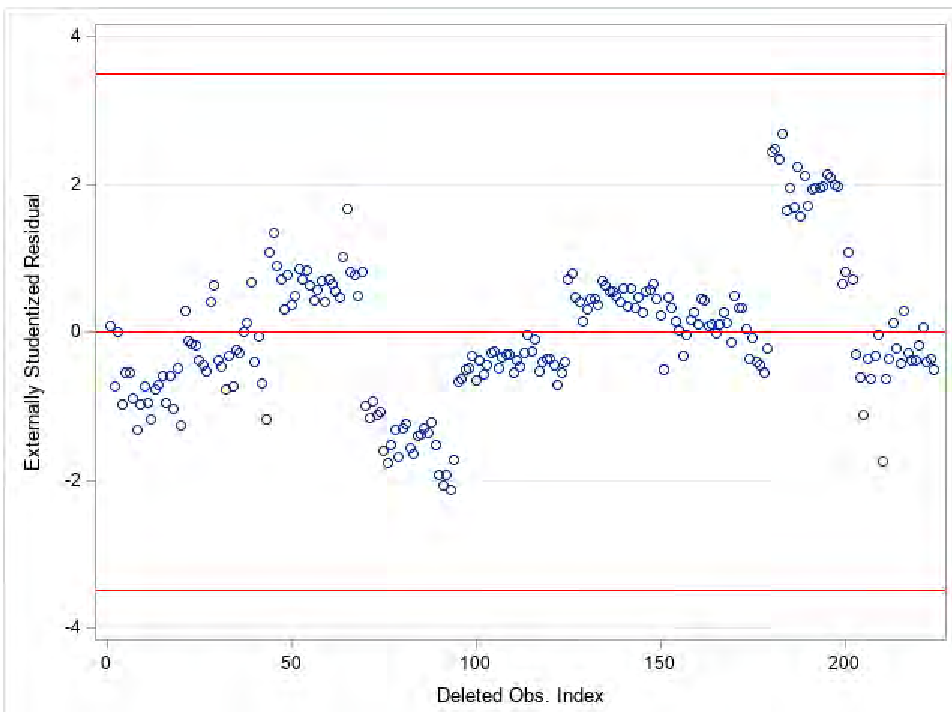

Figure 2.45. Externally studentized residuals for US06 cycle NMOG data.

The solution for fixed effects for the PMI fuel parameter model is presented in Table 2.30. These results indicate that PMI is a statistically significant predictor of NMOG emissions, with a slightly larger model parameter than in the FTP cycle. These results can be used to compute a relative effect of 0.43 percent NMOG emissions per percent PMI change over a PMI range of the test fuels.

Table 2.30. Fixed effect model parameters for US06 NMOG.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-4.7858	0.2388	9.38	-20.04	<.0001
PMI	0.08112	0.02134	104	3.8	0.0002

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.31 presents differences of least squares means for fuel pairs.

Table 2.31. Differences in least squares means by fuel for US06 NMOG.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	0.07995	0.03593	98.5	2.22	0.1792
A	**C**	0.02927	0.03652	93	0.8	0.9296
A	**D**	0.1879	0.03551	102	5.29	<.0001
A	**Base**	0.1014	0.05467	67.4	1.85	0.3515
B	**C**	-0.0507	0.04198	96	-1.21	0.7473
B	**D**	0.1079	0.04109	103	2.63	0.0729
B	**Base**	0.02147	0.05865	78.6	0.37	0.9961
C	**D**	0.1586	0.04164	98.1	3.81	0.0022
C	**Base**	0.07215	0.05899	78.4	1.22	0.738
D	**Base**	-0.0865	0.05819	78.4	-1.49	0.5748

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results show significant differences between fuel pairs A-D and C-D.

2.4.4. CO_2 Emissions

Figure 2.46 provides a graphical overview of CO_2 measurements collected on the FTP cycle, grouped by vehicle. The axis label “index” refers to the count of individual observations. Vehicle means range from about 250 g/mi to about 480 g/mi, with individual vehicle ranges spanning up to 50 g/mi. Veh_C and Veh_H show the largest variability in CO_2 over their fuel and replicate sets.

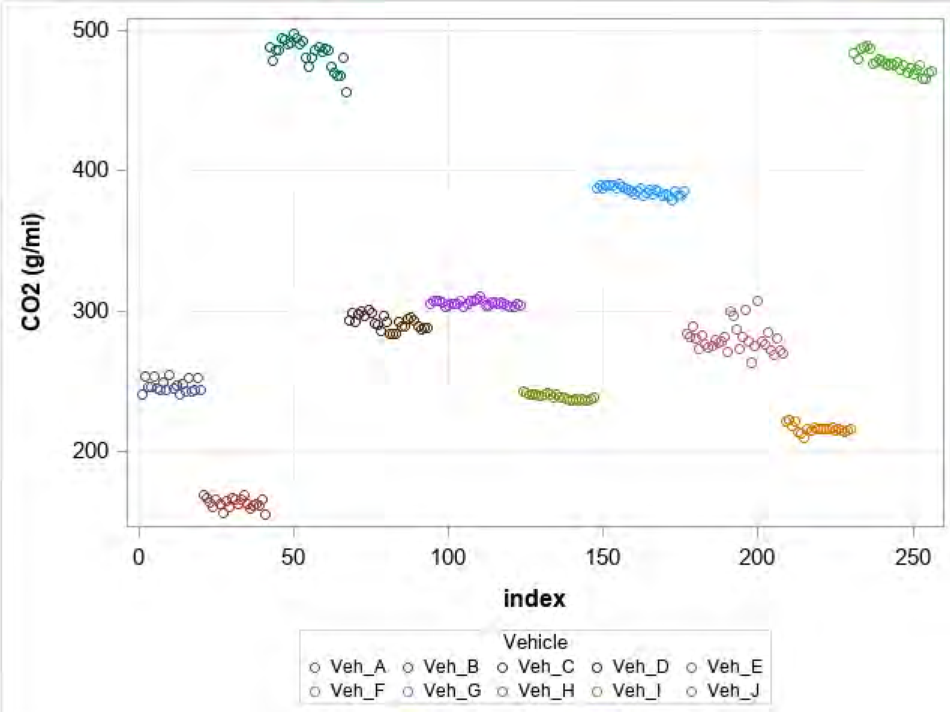

Figure 2.46. FTP CO_2 dataset by vehicle.

Figure 2.47 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.48 shows vehicle means by PM Index, where some vehicles have increasing CO_2 trends with PM Index, and others are flat or decreasing. Table 2.32 summarizes the number of measurements collected and analyzed for each vehicle.

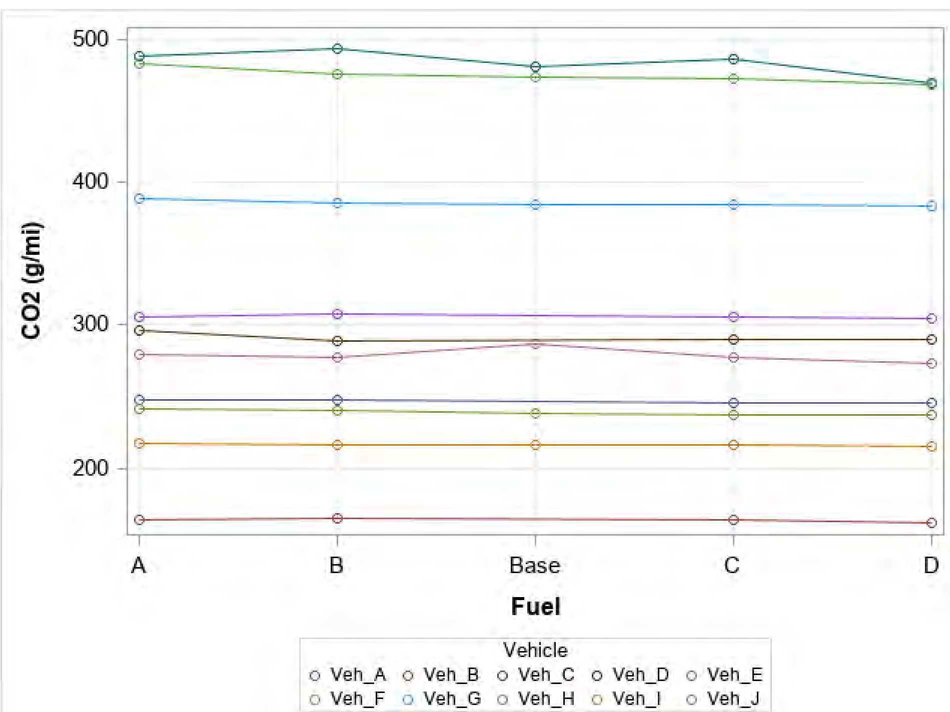

Figure 2.47. FTP CO_2 data as vehicle means by fuel.

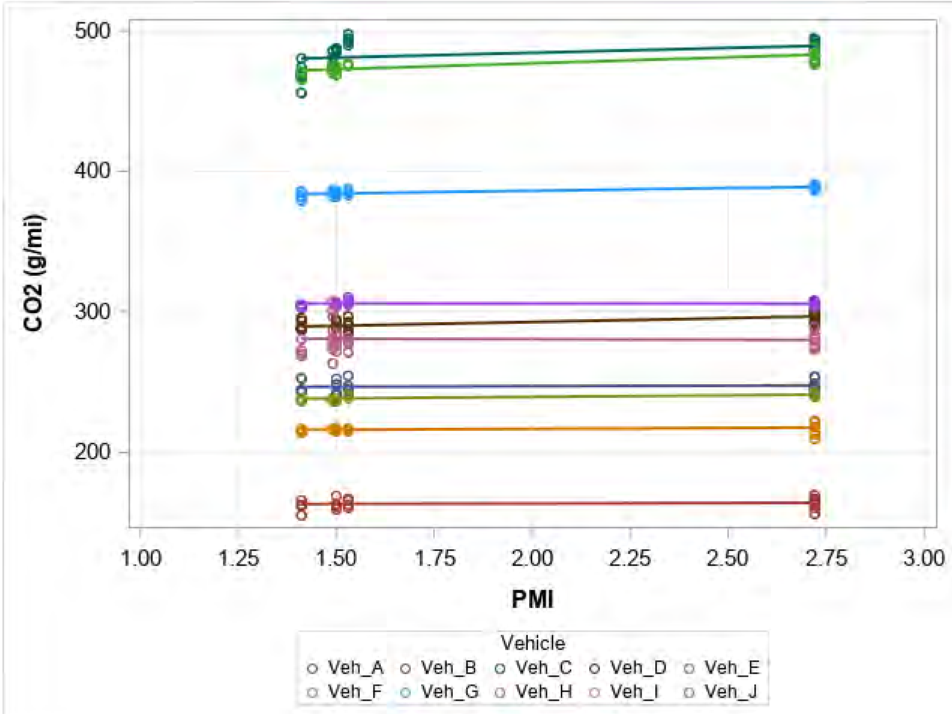

Figure 2.48. FTP CO_2 data as vehicle means by PM Index.

Table 2.32. Number of CO_2 measurements collected and analyzed in the FTP cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	21	26	26	30	24	29	32	22	26	256

Data analysis was performed using the SAS software package (current version). Unlike other emissions in this study, no log-transformation was applied to the CO_2 data as the distribution of points generally falls within a narrow band defined by the vehicle efficiency and test cycle energy requirement.

The SAS Mixed procedure was used with the restricted maximum likelihood (REML) method to generate covariance parameter estimates and to assess the behavior of residuals. In this case, covariance parameters were generated for the dataset as a whole, rather than on a per-vehicle basis as for other emissions in this study, as the latter did not produce a significant improvement in model fit. Figure 2.49 indicates conditional studentized residuals show a relatively narrow distribution with some extension toward the tails. Figure 2.50 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points are well within the acceptable range.

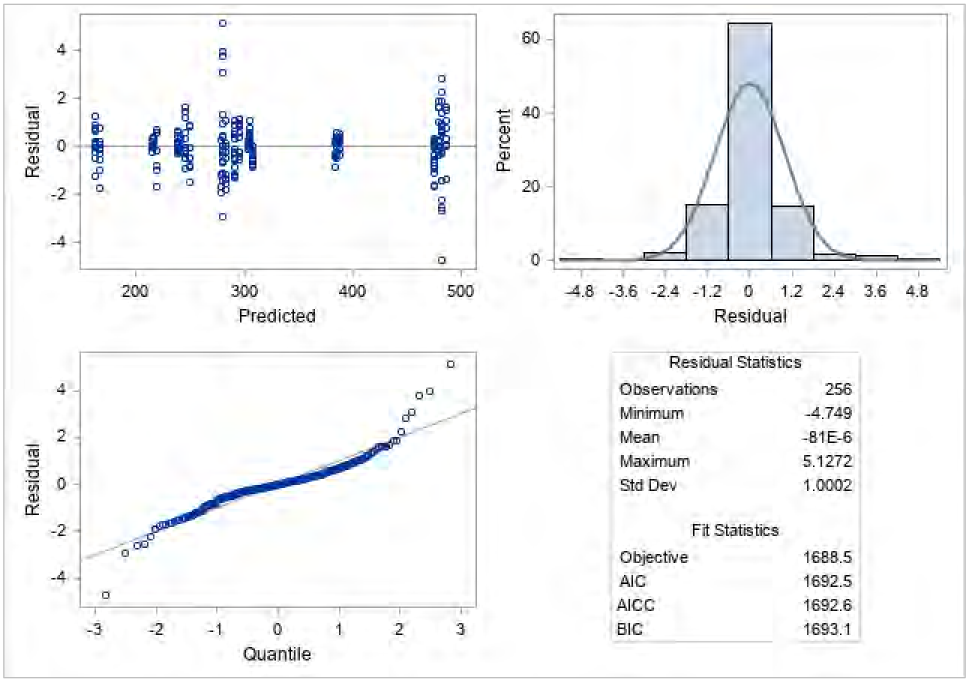

Figure 2.49. Analysis of conditional studentized residuals for FTP cycle CO_2 data.

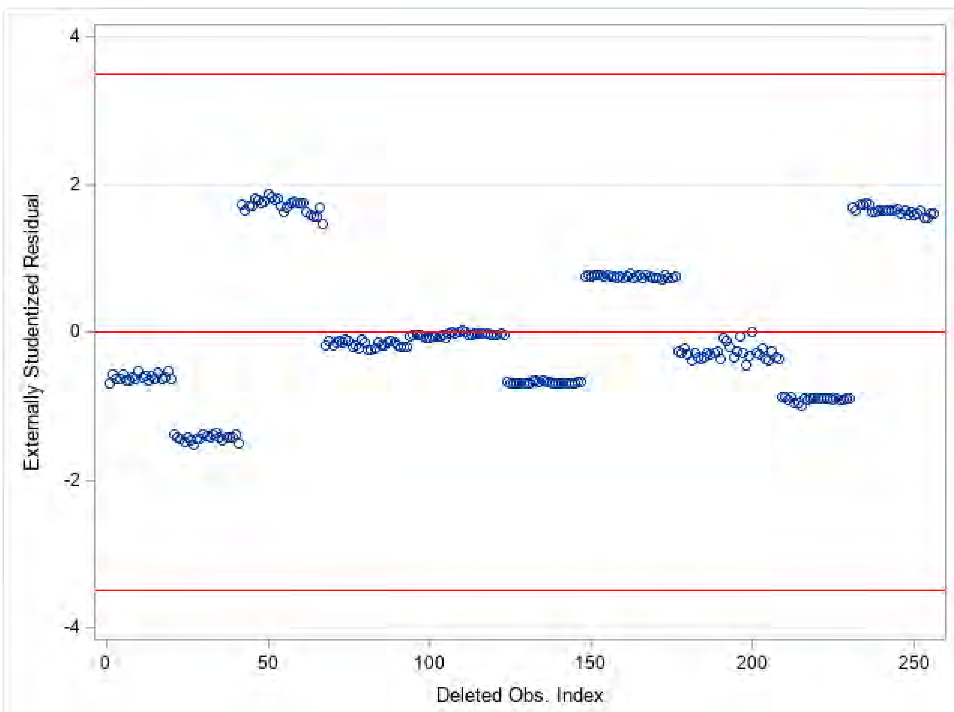

Figure 2.50. Externally studentized residuals for FTP cycle CO_2 data.

Following this initial analysis, the model was refit using the maximum likelihood method to generate the intercept and fixed effect coefficient for the PMI fuel term. The model parameters and related fit statistics are presented in Table 2.33. These results indicate that PMI is a highly significant predictor of CO_2 emissions over the FTP cycle, but with a relatively small effect on the order of 1% per PMI unit.

Table 2.33. PMI model parameters for FTP CO_2.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	303.46	32.2644	10	9.41	<.0001
PMI	2.9227	0.5914	246	4.94	<.0001

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.34 presents differences of least squares means for fuel pairs.

Table 2.34. Differences in least squares means by fuel for FTP CO_2.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	1.515	0.9688	246	1.56	0.5221
A	**C**	3.3537	0.9819	246	3.42	0.0066
A	**D**	6.561	0.9553	246	6.87	<.0001
A	**Base**	1.0635	1.2101	246	0.88	0.9045
B	**C**	1.8387	1.1258	246	1.63	0.4776
B	**D**	5.046	1.1028	246	4.58	<.0001
B	**Base**	-0.4515	1.3335	246	-0.34	0.9972
C	**D**	3.2073	1.1144	246	2.88	0.035
C	**Base**	-2.2902	1.3438	246	-1.7	0.4332
D	**Base**	-5.4975	1.3236	246	-4.15	0.0004

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. The results show significant differences between Fuel D and the other fuels.

US06 Cycle Data

Presentation of the US06 CO_2 results will follow the same outline as for the FTP cycle. Figure 2.51 provides a graphical overview of the measurements collected on the US06 test cycle, grouped by vehicle. The axis label "index" refers to the count of individual observations. Vehicle means range from about 220 g/mi to about 520 g/mi, with individual vehicle ranges spanning up to 80 g/mi. Veh_C shows significantly larger variability over its fuel and replicate sets than the other vehicles.

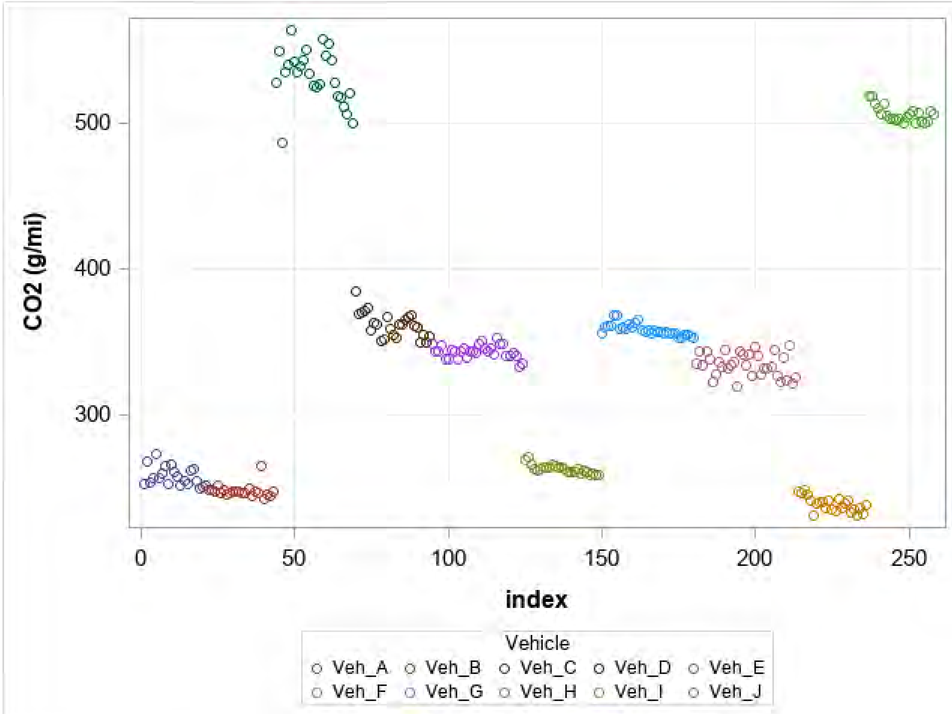

Figure 2.51. US06 CO_2 dataset by vehicle.

Figure 2.52 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure 2.53 presents vehicle means by PM Index. Similar to the FTP cycle, some vehicles have increasing CO_2 trends with increasing PM Index, while others are flat or slightly decreasing. Table 2.35 summarizes the number of measurements collected and analyzed for each vehicle.

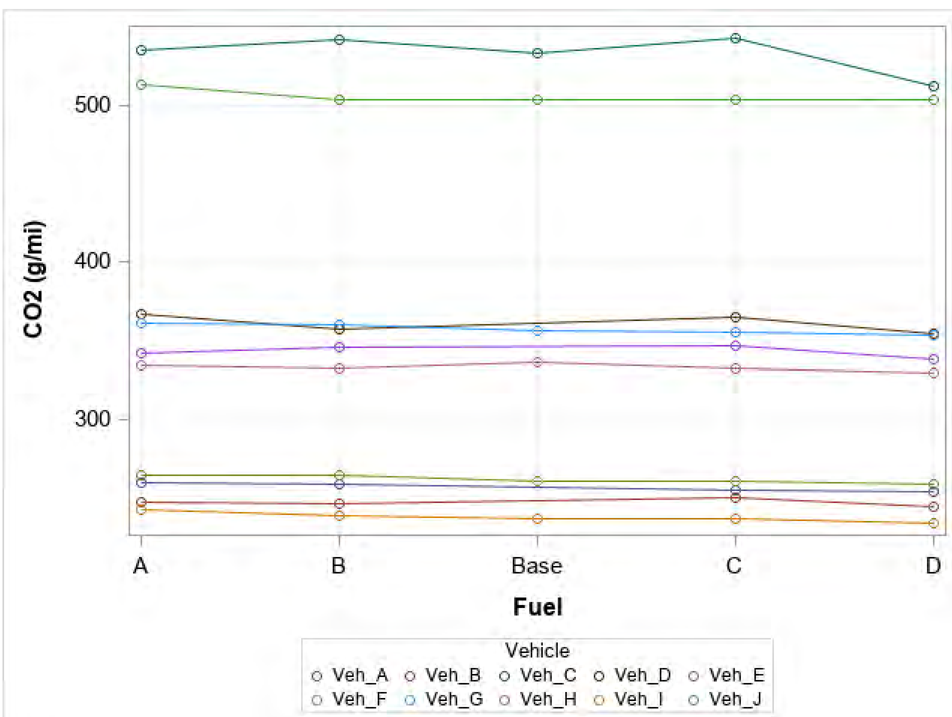

Figure 2.52. US06 CO_2 data as vehicle means by fuel.

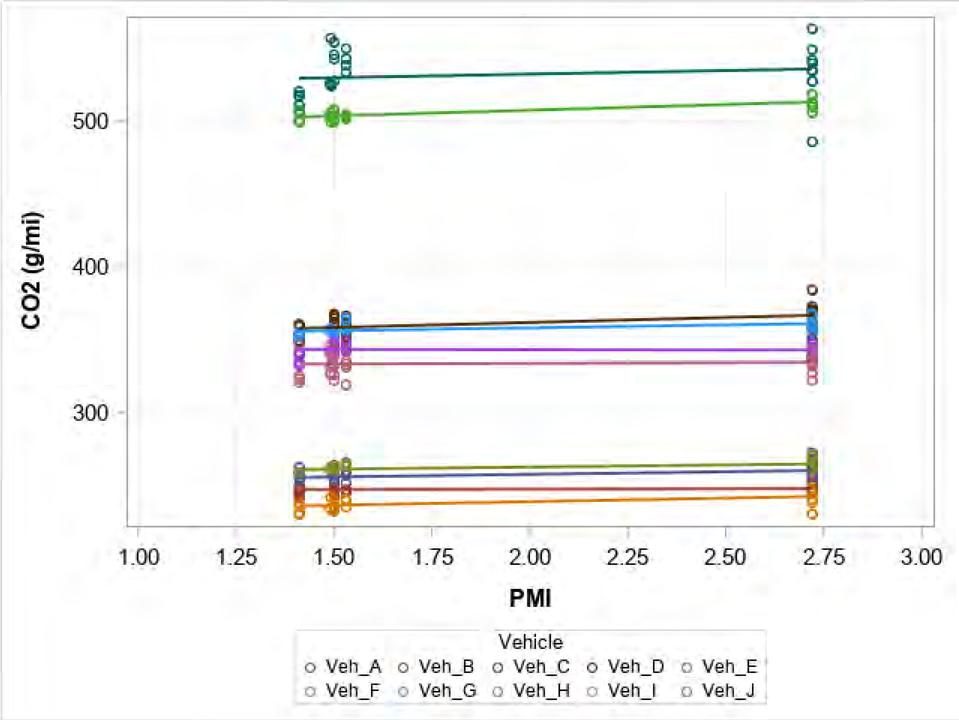

Figure 2.53. US06 CO_2 data as vehicle means by PM Index.

Table 2.35. Number of CO_2 measurements collected and analyzed in the US06 cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	23	26	25	30	25	31	33	23	22	258

Data analysis and model fitting proceeded in the same manner as for the FTP cycle as described above. Figure 2.54 indicates that conditional studentized residuals show a relatively narrow distribution with some extension toward the tails. Figure 2.55 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points are well within the acceptable range.

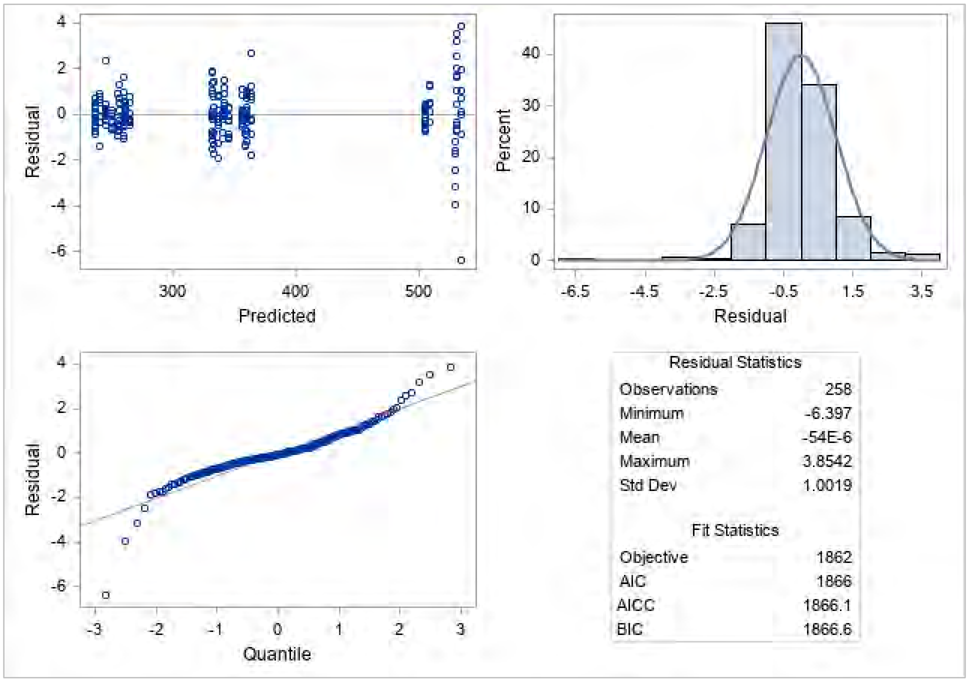

Figure 2.54. Analysis of conditional studentized residuals for US06 cycle CO_2 data.

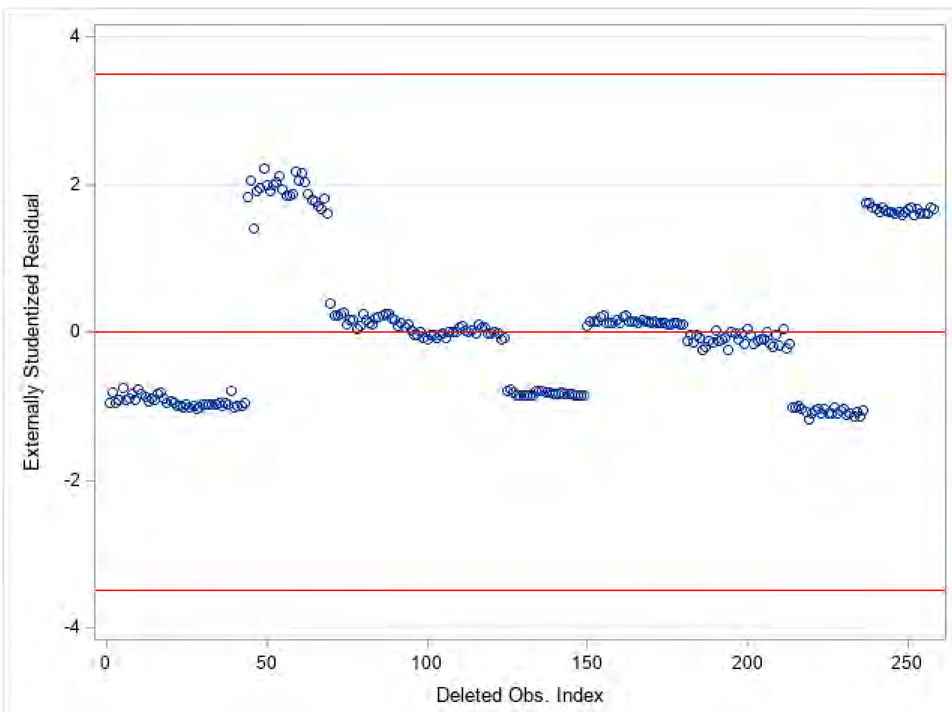

Figure 2.55. Externally studentized residuals for US06 cycle CO_2 data.

The solution for fixed effects for the PMI fuel parameter model is presented in Table 2.36. Similar to the FTP cycle, these results indicate that PMI is a highly significant predictor of CO_2 emissions over the US06, but with a relatively small effect, on the order of 1% per PMI unit.

Table 2.36. Fixed effect model parameters for US06 CO_2.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	337.58	31.1952	10.1	10.82	<.0001
PMI	3.344	0.8242	248	4.06	<.0001

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table 2.37 presents differences of least squares means for fuel pairs.

Table 2.37. Differences in least squares means by fuel for US06 CO_2.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adjusted P
A	**B**	1.7458	1.3285	248	1.31	0.6827
A	**C**	1.5395	1.3382	248	1.15	0.7794
A	**D**	8.8066	1.3206	248	6.67	<.0001
A	**Base**	2.4002	1.6489	248	1.46	0.5923
B	**C**	-0.2062	1.5251	248	-0.14	0.9999
B	**D**	7.0609	1.5093	248	4.68	<.0001
B	**Base**	0.6544	1.8052	248	0.36	0.9963
C	**D**	7.2671	1.5192	248	4.78	<.0001
C	**Base**	0.8607	1.8061	248	0.48	0.9894
D	**Base**	-6.4064	1.7983	248	-3.56	0.004

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. Similar to the FTP cycle, results show significant differences between Fuel D and the other fuels.

2.4.5. Influence of Drive Quality

The data review and analysis presented so far examined the emissions measurements themselves, including statistical confidence for the fuel effects and influence of any particular vehicle or observation. In addition, the fitting of individual variance models for each vehicle before computing the overall effect of PMI or test fuel further served to mitigate influence of the vehicle or the test lab.

Throughout the testing, the program participants recorded SAE Drive Quality Metrics (DQMs), which evaluate conformity between the actual and target drive speeds for chassis dynamometer tests. [13] The DQMs combine the speed variances with other information about the vehicle and test cycle to compute parameters such as the Energy Economy Ratio (EER), Absolute Speed Change Rating (ASCR), and Inertial Work Rating (IWR). Each metric represents a relative variance (i.e., percentage), with values close to zero indicating that a vehicle followed the speed versus time trace more closely. Negative numbers indicate slightly lower speeds and accelerations relative to the specified procedure while positive values indicate slightly higher speeds and accelerations. Statistical analysis of DQMs can provide an indication of the influence of variation in vehicle operation on the study results. After an initial review of the DQM values across the dataset, IWR was chosen as the parameter to use for this assessment.

Table 2.38 and Table 2.39 present differences of least squares means by fuel for IWR over the FTP and US06 cycles, respectively. Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. The results show no significant differences in inertial work among the test fuel comparisons except in one pair (Fuel D vs A in the FTP cycle). This suggests that the driver or other conditions related to vehicle operation had no significant influence the fuel effects observed.

Table 2.38. Differences in least squares means by fuel for FTP cycle IWR.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adj P
A	**B**	0.1129	0.0426	47.9	2.65	0.0770
A	**C**	0.0512	0.0403	43.9	1.27	0.7099
A	**D**	0.1417	0.0384	41.8	3.69	0.0055
A	**Base**	0.0793	0.0485	43.7	1.63	0.4840
B	**C**	-0.0618	0.0489	48	-1.26	0.7154
B	**D**	0.0287	0.0474	46.6	0.61	0.9735
B	**Base**	-0.0337	0.0559	46.7	-0.6	0.9741
C	**D**	0.0905	0.0453	43.4	2	0.2852
C	**Base**	0.0281	0.0542	44.5	0.52	0.9850
D	**Base**	-0.0624	0.0528	43.4	-1.18	0.7610

Table 2.39. Differences in least squares means by fuel for US06 cycle IWR.

Fuel1	Fuel2	Estimate	Standard Error	DF	t Value	Adj P
A	**B**	0.0833	0.0804	51.6	1.04	0.8377
A	**C**	0.0270	0.0803	51.6	0.34	0.9972
A	**D**	0.0153	0.0768	48.5	0.2	0.9996
A	**Base**	-0.0982	0.0883	48.1	-1.11	0.7993
B	**C**	-0.0563	0.0937	52.7	-0.6	0.9743
B	**D**	-0.0680	0.0908	50.4	-0.75	0.9437
B	**Base**	-0.1815	0.1007	49.7	-1.8	0.3839
C	**D**	-0.0117	0.0907	50.4	-0.13	0.9999
C	**Base**	-0.1252	0.1006	49.7	-1.24	0.7259
D	**Base**	-0.1135	0.0978	47.8	-1.16	0.7737

3. Summary and Conclusions

This study collected PM and gaseous emissions data from a test fleet of ten popular light-duty gasoline vehicles spanning model years 2015-2022 using five test fuels blended to represent replacement of a portion of heavy aromatics with alternate octane sources.

The emissions analysis provided two levels of results: an overall effect of PM Index (PMI) that incorporates data from all test fuels, and a set of fuel-to-fuel comparisons to evaluate the impact of specific blending changes. Comparisons between the fuels indicate that replacement of approximately 3 v% of C_{10}+ aromatics with alternate octane sources provides significant PM reductions in all cases, with non-aromatic alternatives producing the largest effect. The overall results indicate a significant sensitivity of PM emissions to PMI over both the FTP and US06 test cycles, with a directionally consistent response from all vehicles over the FTP cycle and all vehicles except one over the US06.

Table 3.1 presents percent-PM-emission per percent-PMI sensitivities (or ratios) by test cycle and vehicle. The vehicles are sorted from smallest to largest effect for the FTP and span a range of approximately 1.0 to 2.2. For the US06 cycle, the range is approximately 0.5 to 2.3 if the value for Veh_G is excluded. (A review of data for Veh_G finds it has a relatively low sensitivity to PMI over the US06, which allows a few influential measurements to tip the average value in the opposite direction of the other vehicles.)

Table 3.1. Percent-PM-emissions per percent-PM-Index sensitivities by test cycle and vehicle.

	Veh_H	Veh_E	Veh_A	Veh_C	Veh_D	Veh_J	Veh_B	Veh_F	Veh_I	Veh_G
FTP	1.01	1.08	1.20	1.21	1.34	1.47	1.55	1.66	1.83	2.15
US06	0.51	0.44	1.67	0.80	1.15	1.42	0.64	1.22	2.27	-0.12

Data analysis also included gaseous emissions, which are of interest when considering broader air quality impacts of fuel formulation changes. Table 3.2 presents a summary of overall test-fleet-average effects of PMI on PM, NOx, NMOG, and CO_2 emissions for the FTP and US06 test cycles.

Table 3.2. Summary of model results for a PM Index reduction from 2.5 to 1.5.

	FTP Cycle		US06 Cycle	
	% emission change from 2.5 to 1.5 PMI	% emission change per % PMI	% emission change from 2.5 to 1.5 PMI	% emission change per % PMI
PM	-58%	1.45	-40%	1.00
NOx	*NSS*[a]	*NSS*[a]	-10%	0.25
CO_2	-1%	0.02	-1%	0.02
NMOG	-9%	0.22	-17%	0.43

[a]Not statistically significant at the $p \leq 0.05$ level.

These results indicate that the largest impact of the fuel changes being investigated was the reduction of PM emissions, and that no increase in emissions of NOx, NMOG, nor CO_2 was observed for the test fleet overall when replacing a portion of heavy aromatics with alternate octane sources.

Acknowledgement

The U.S. EPA Office of Transportation and Air Quality acknowledges significant contributions by Environment and Climate Change Canada (ECCC) and the seven participating global automotive vehicle manufacturers in producing fuel chemistry and emissions data for this study.

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Appendix A:

Supplemental Emissions Analysis

A1. Carbon Monoxide

FTP Cycle Data

Figure A1.1 and Figure A1.2 provide a graphical overview of carbon monoxide (CO) measurements collected on the FTP cycle, grouped by vehicle, on linear and log scales, respectively. The axis label "index" refers to the count of individual observations. Vehicle means cover a wide range, from about 10 mg/mi to over 600 mg/mi, with individual vehicle ranges spanning about 25 mg/mi to over 250 mg/mi.

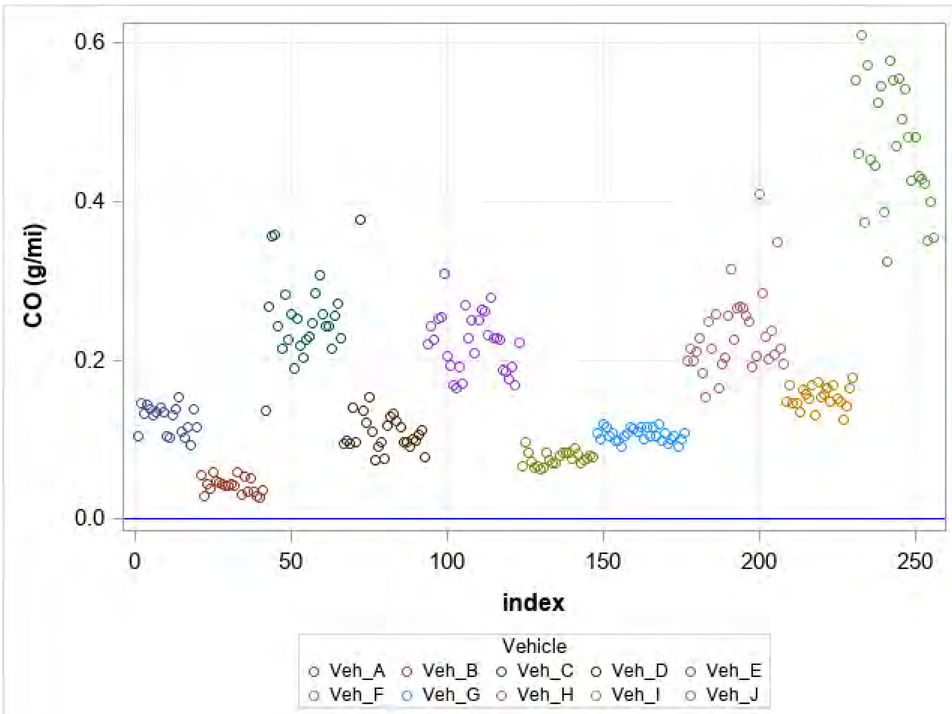

Figure A1.1. FTP CO dataset by vehicle, linear scale.

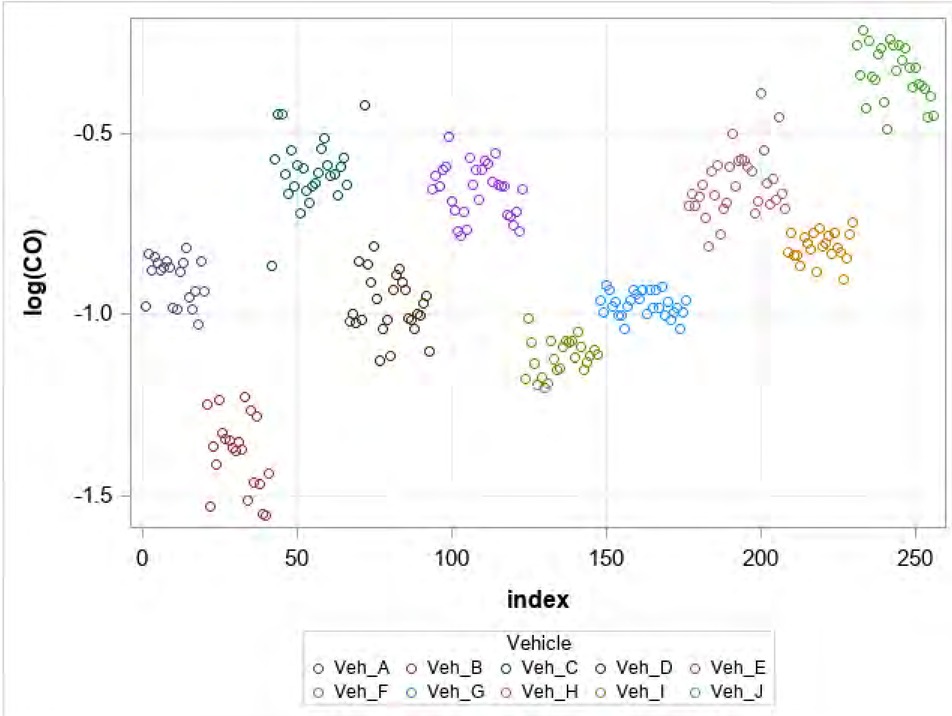

Figure A1.2. FTP CO dataset by vehicle, log scale.

Figure A1.3 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure A1.4 shows vehicle means by PM Index, where some vehicles have increasing CO trends with PM Index, and others flat or decreasing. Table A1.1 summarizes the number of measurements collected and analyzed for each vehicle.

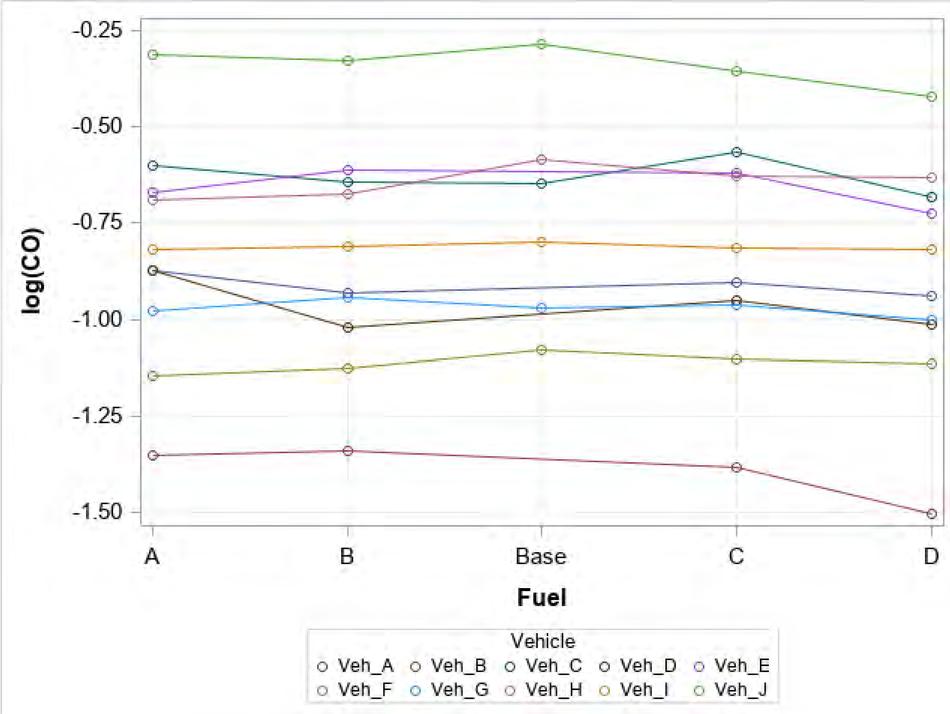

Figure A1.3. FTP CO data as vehicle means by fuel, log scale.

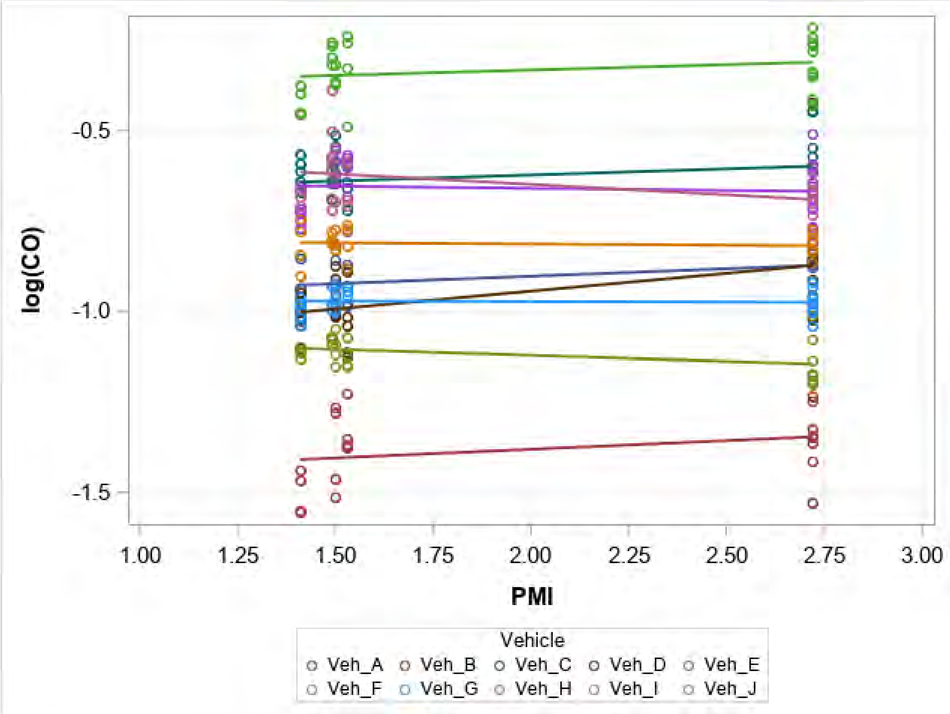

Figure A1.4. FTP CO data as vehicle means by PM Index, log scale.

Table A1.1. Number of CO measurements collected and analyzed in the FTP cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	21	26	26	30	24	29	32	22	26	256

Data analysis was performed using the SAS software package (current version). All CO emissions data were log-transformed before model fitting began. This is a common practice, as vehicle emissions tend to follow approximately log-normal distributions. In addition, this transformation is a standard approach to normalizing the distributions of residuals and stabilizing their variance across a range of emission levels.[1]

The SAS Mixed procedure was used with the restricted maximum likelihood (REML) method in an initial round of model fitting to examine the behavior of residuals and assess the effect of generating covariance parameters specific to each vehicle. Figure A1.5 indicates conditional studentized residuals are normally distributed with some minor deviation at the tails. Figure A1.6 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for "outlier points". Results indicate all points fall within the acceptable range.

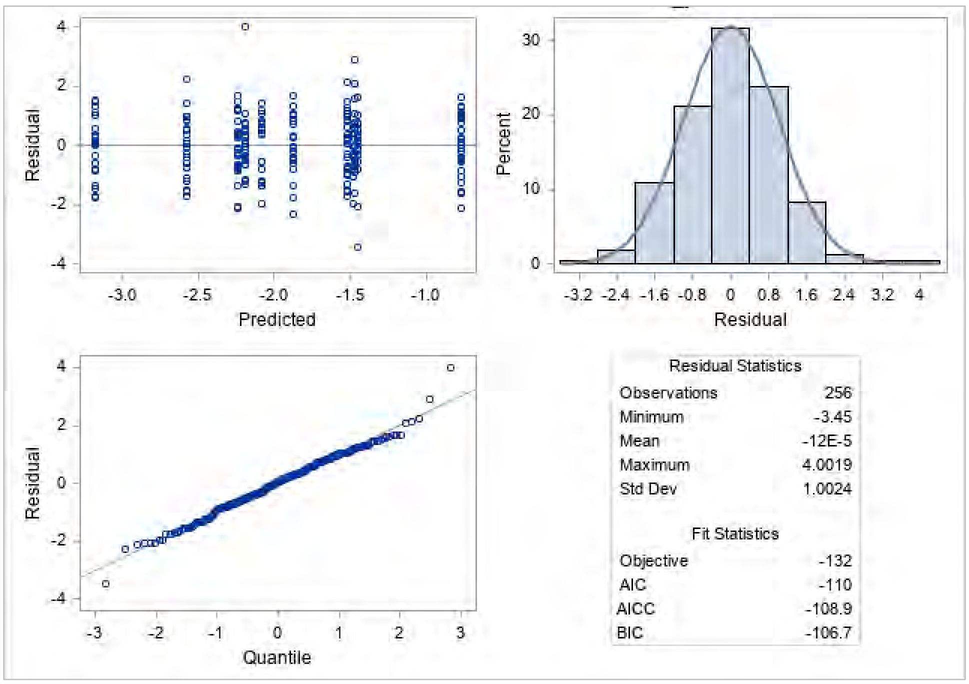

Figure A1.5. Analysis of conditional studentized residuals for FTP cycle CO data.

[1] Additional discussion is available in Section 5.1 of the EPAct study report, EPA-420-R-13-002, April 2013.

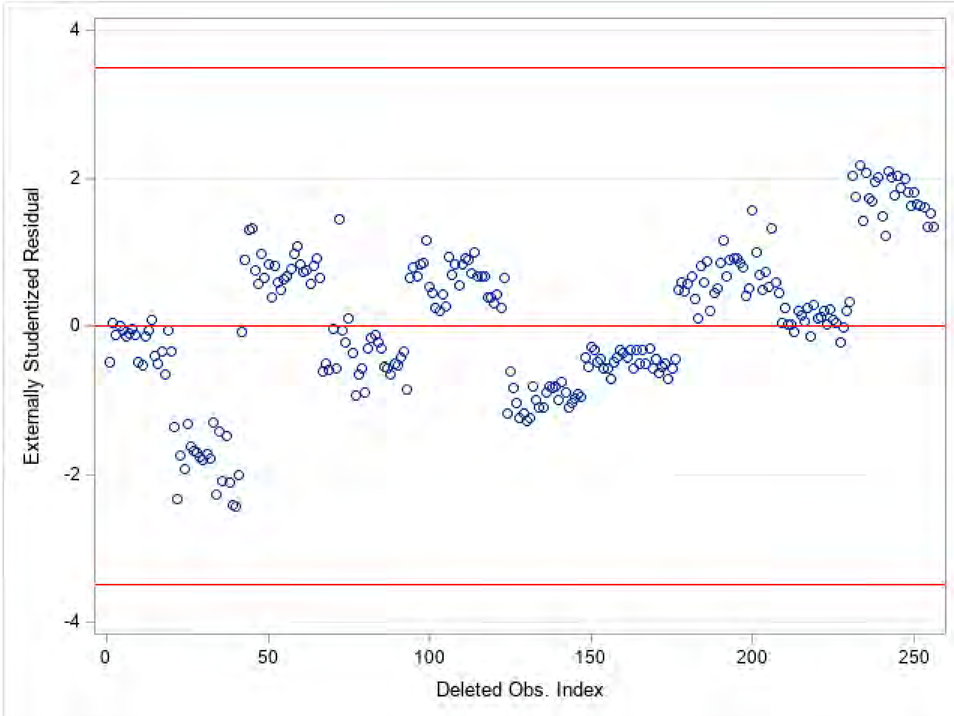

Figure A1.6. Externally studentized residuals for FTP cycle CO data.

Following this initial analysis, the model was refit using the maximum likelihood method to generate the intercept and fixed effect coefficient for the PMI fuel term. The model parameters and related fit statistics are presented in Table A1.2. These results indicate that PMI is not a significant predictor of CO emissions in the FTP cycle.

Table A1.2. PMI model parameters for FTP CO.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-1.9293	0.2056	10.3	-9.38	<.0001
PMI	-0.00317	0.01511	130	-0.21	0.8343

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table A1.3 presents differences of least squares means for fuel pairs.

Table A1.3. Differences in least squares means by fuel for FTP CO.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adj P
A	**B**	-0.0319	0.0256	133	-1.25	0.7219
A	**C**	-0.0312	0.0250	118	-1.25	0.7220
A	**D**	0.0638	0.0242	111	2.63	0.0712
A	**Base**	-0.0612	0.0298	106	-2.05	0.2481
B	**C**	0.0007	0.0295	130	0.02	1.0000
B	**D**	0.0958	0.0289	126	3.31	0.0104
B	**Base**	-0.0293	0.0337	117	-0.87	0.9076
C	**D**	0.0950	0.0284	115	3.35	0.0095
C	**Base**	-0.0300	0.0333	111	-0.90	0.8958
D	**Base**	-0.1250	0.0327	107	-3.82	0.0021

Differences in Table A1.3 are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results indicate the largest differences occurred between Fuel D and the other fuels.

US06 Cycle Data

Figure A1.7 provides an initial review of CO measurements collected on the US06 test cycle, grouped by vehicle. The axis label "index" refers to the count of individual observations. The red arrows highlight measurements for Veh_I, which are nearly identical in value for all tests. Given the implausibility of this situation, a decision was made to remove this vehicle's US06 CO data from subsequent analysis. The remaining data is shown in Figure A1.8 and Figure A1.9 (log and linear scales, respectively), where the vehicle means fall between roughly 40 mg/mi and 6 g/mi, except for Veh_J that had a mean around 8 g/mi and a large span.

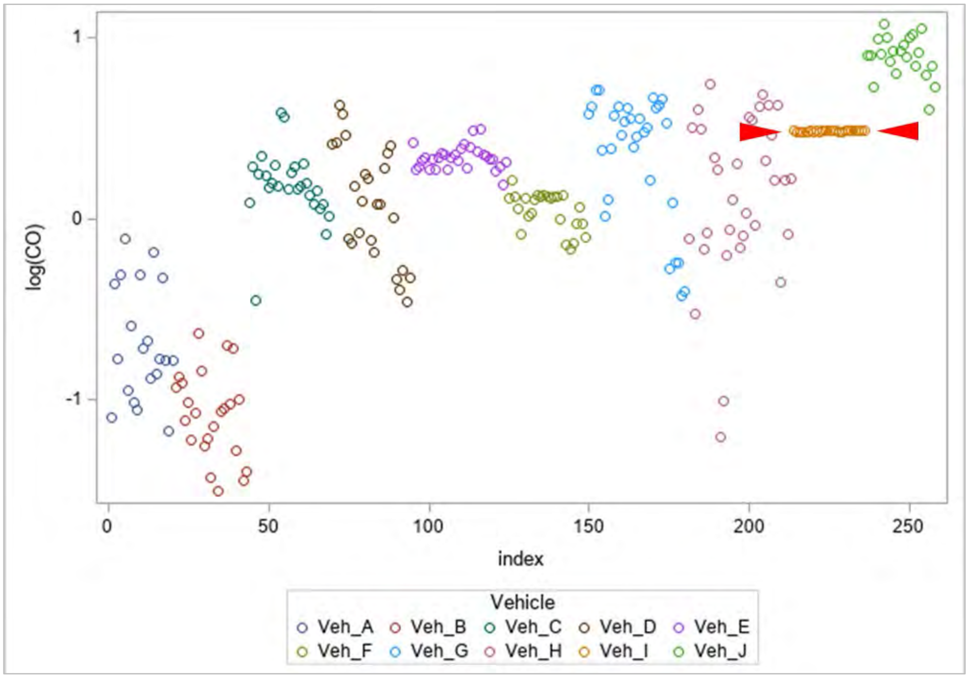

Figure A1.7. Initial review of US06 CO dataset by vehicle, log scale. Red arrows indicate suspect measurements.

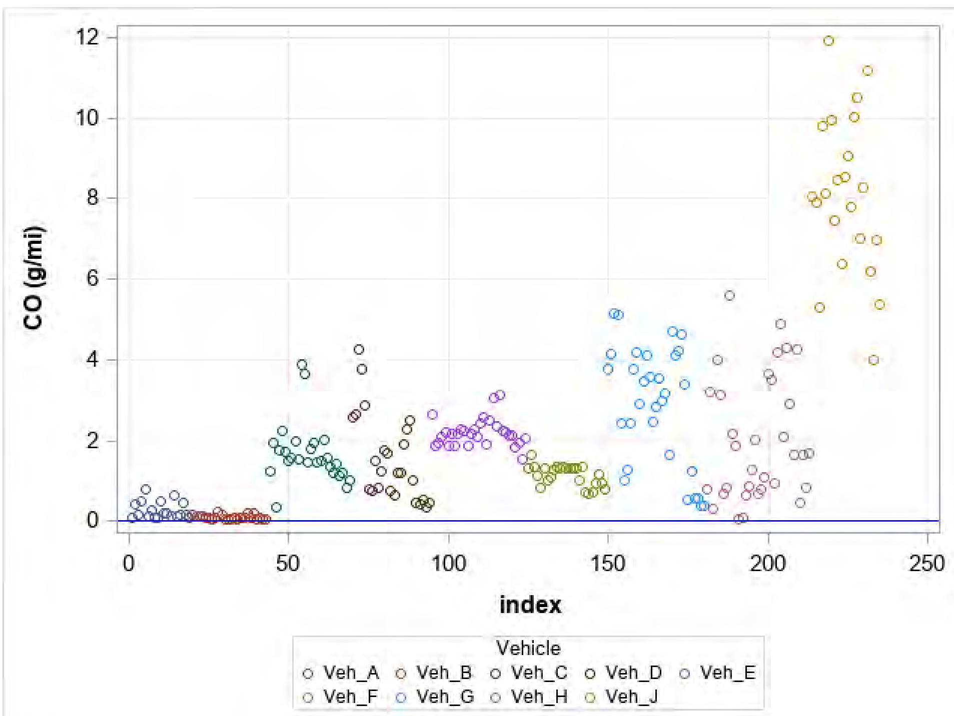

Figure A1.8. US06 CO dataset used in the analysis, linear scale.

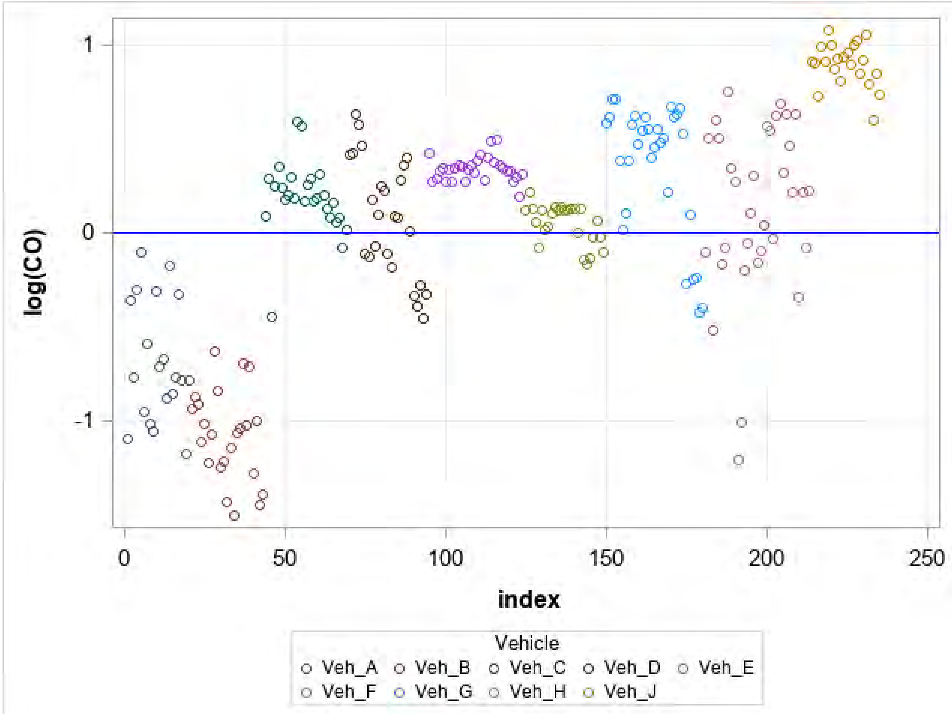

Figure A1.9. US06 CO dataset used in the analysis, log scale.

Figure A1.10 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure A1.11 presents vehicle means by PM Index. Similar to the FTP cycle, some vehicles have increasing CO trends with increasing PM Index, while others are flat or slightly decreasing. Table A1.4 summarizes the number of measurements collected and analyzed for each vehicle.

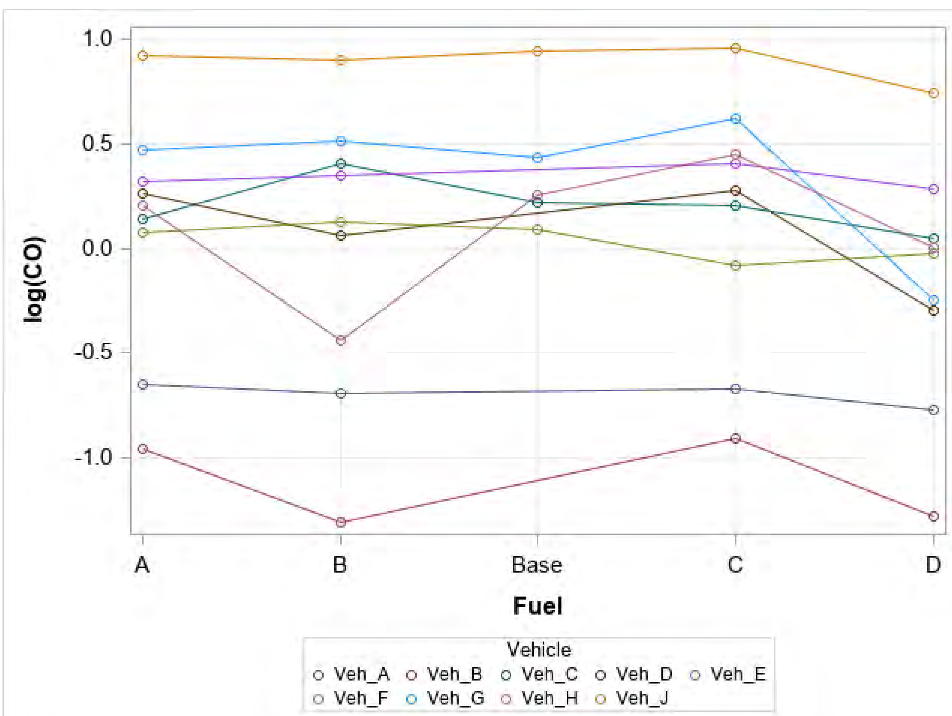

Figure A1.10. US06 CO data as vehicle means by fuel, log scale.

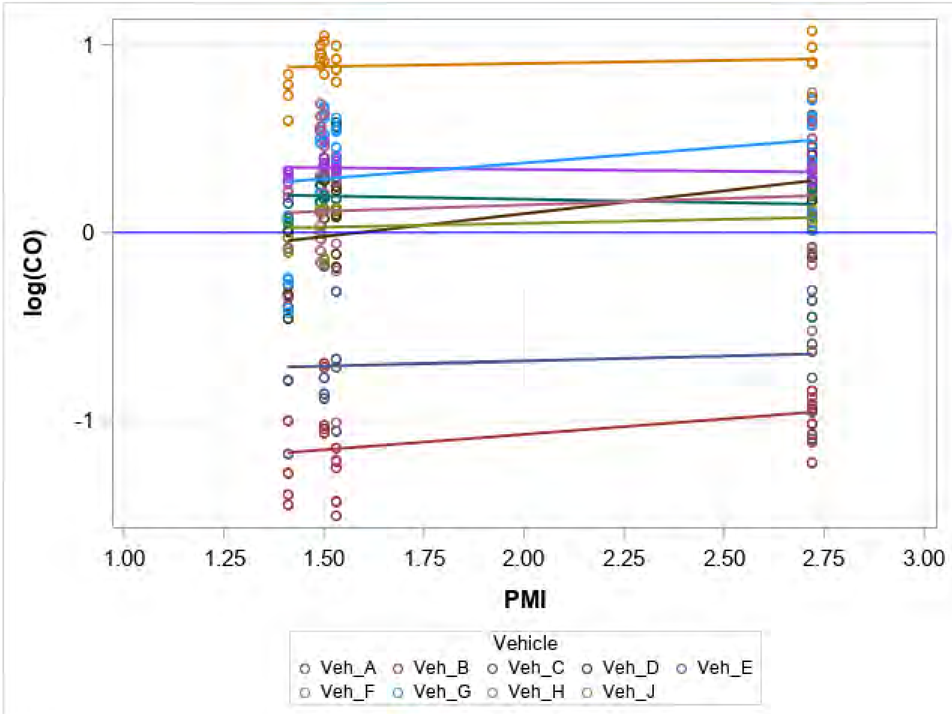

Figure A1.11. US06 CO data as vehicle means by PM Index, log scale.

Table A1.4. Number of CO measurements collected and analyzed in the US06 cycle model fitting.

	Veh_A	**Veh_B**	**Veh_C**	**Veh_D**	**Veh_E**	**Veh_F**	**Veh_G**	**Veh_H**	**Veh_I**	**Veh_J**	**Total**
Measurements collected	20	23	26	25	30	25	31	33	23	22	258
Measurements removed	0	0	0	0	0	0	0	0	23	0	23
Used in analysis	**20**	**23**	**26**	**25**	**30**	**25**	**31**	**33**	**0**	**22**	**235**

Data analysis and model fitting proceeded in the same manner as for the FTP cycle as described above, including log transformation of the data and generation of covariance parameter estimates on a per-vehicle basis. Figure A1.12 indicates conditional studentized residuals are approximately normally distributed with some deviation toward the left tail. Figure A1.13 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points fall within the acceptable range.

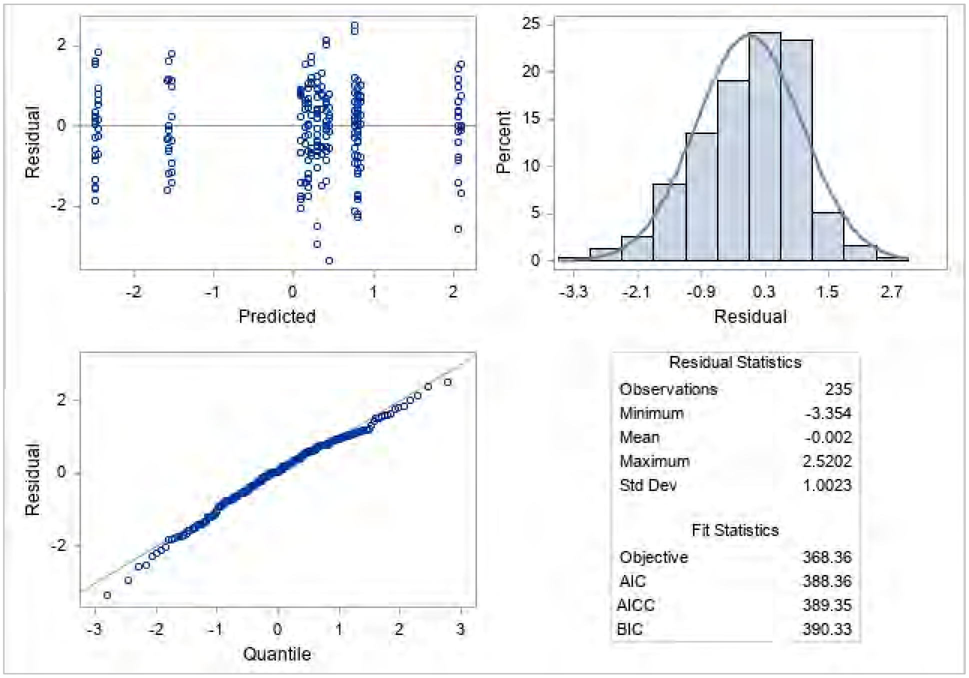

Figure A1.12. Analysis of conditional studentized residuals for US06 cycle CO data.

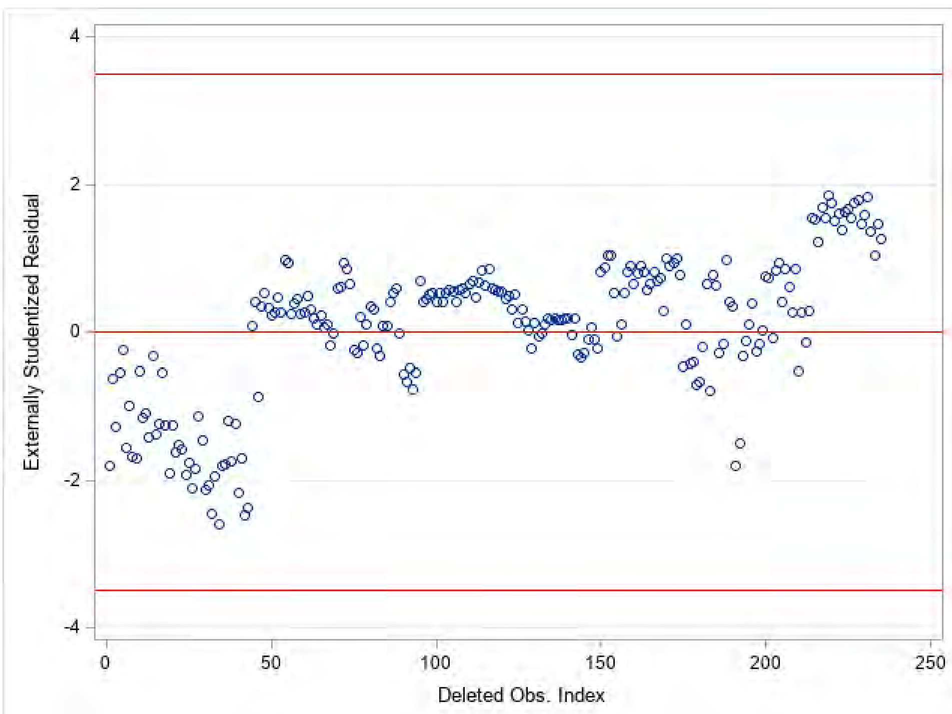

Figure A1.13. Externally studentized residuals for US06 cycle CO data.

The solution for fixed effects for the PMI fuel parameter model is presented in Table A1.5. These results indicate that PMI is not a significant predictor of CO emissions for the US06 cycle.

Table A1.5. Fixed effect model parameters for US06 CO.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	0.0065	0.4287	9.46	0.02	0.9883
PMI	0.0347	0.0363	74.9	0.95	0.3427

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table A1.6 presents differences of least squares means for fuel pairs.

Table A1.6. Differences in least squares means by fuel for US06 CO.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adj P
A	**B**	-0.0243	0.0538	55.3	-0.45	0.9911
A	**C**	-0.1216	0.0539	54.7	-2.26	0.1754
A	**D**	0.2351	0.0536	56.2	4.39	0.0005
A	**Base**	-0.1249	0.0871	68.7	-1.43	0.6077
B	**C**	-0.0973	0.0619	55.9	-1.57	0.5210
B	**D**	0.2594	0.0616	57.1	4.21	0.0008
B	**Base**	-0.1006	0.0919	76.9	-1.09	0.8090
C	**D**	0.3567	0.0617	56.6	5.78	<.0001
C	**Base**	-0.0033	0.0920	76.9	-0.04	1.0000
D	**Base**	-0.3600	0.0917	77.0	-3.93	0.0017

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results, like for the FTP, show the largest differences between Fuel D and the other fuels.

A2. Fuel Economy

FTP Cycle Data

Figure A2.1 provides a graphical overview of carbon-balance fuel economy (CBFE) measurements collected on the FTP cycle, grouped by vehicle. The term “carbon balance” describes the computation process, which sums up all the carbon in the exhaust emissions and computes the equivalent gasoline volume using the carbon content and density of the test fuel. This method does not apply any adjustments to represent a regulatory CAFE result. The axis label “index” refers to the count of individual observations. Vehicle means cover a wide range, from about 12 mpg to around 56 mpg.

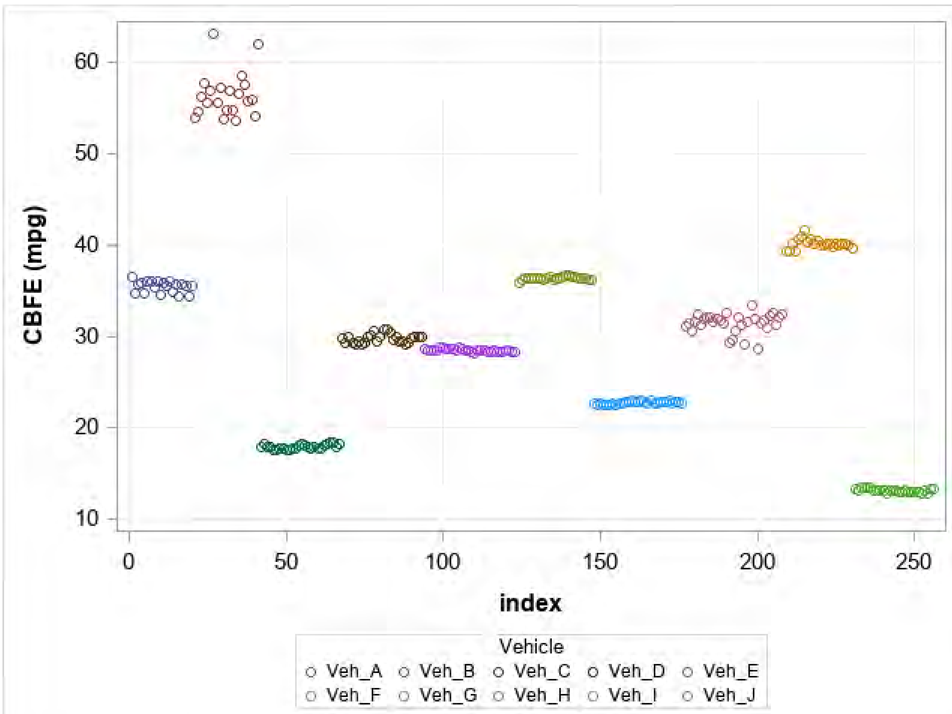

Figure A2.1. FTP CBFE dataset by vehicle.

Figure A2.2 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel) and Figure A2.3 shows vehicle means by PM Index. Table A2.1 summarizes the number of measurements collected and analyzed for each vehicle.

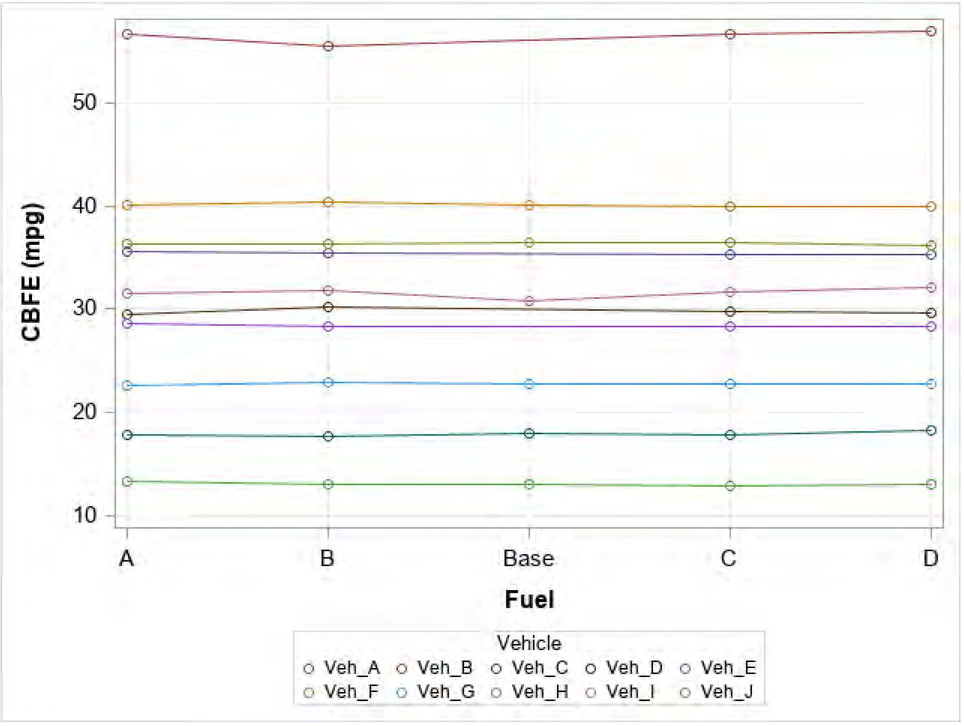

Figure A2.2. FTP CBFE data as vehicle means by fuel.

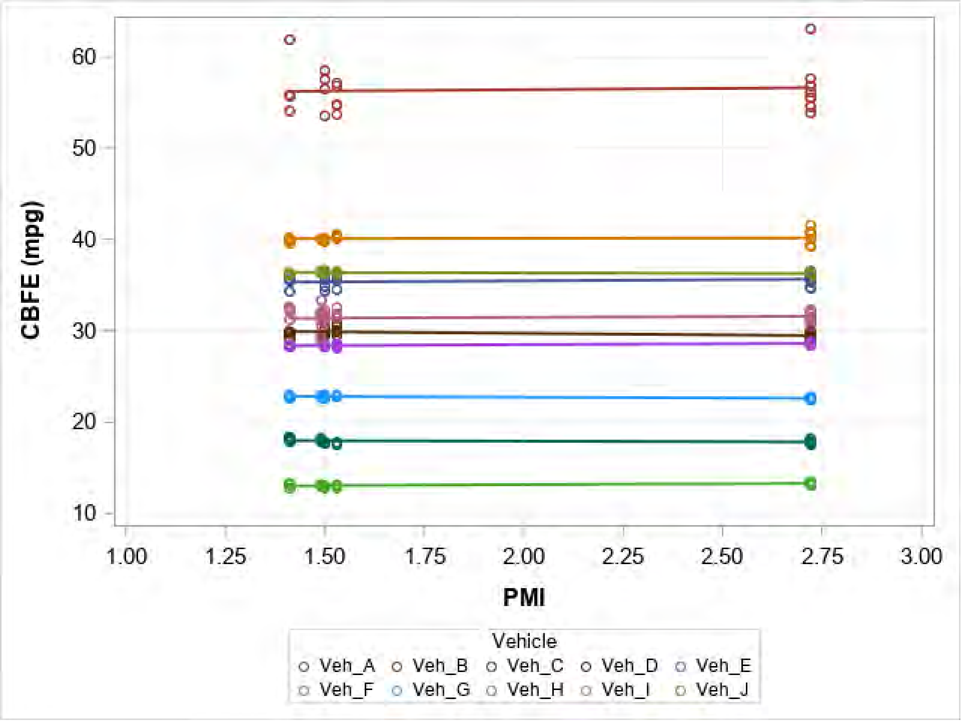

Figure A2.3. FTP CBFE data as vehicle means by PM Index.

Table A2.1. Number of CBFE measurements collected and analyzed in the FTP cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	21	26	26	30	24	29	32	22	26	256

Data analysis was performed using the SAS software package (current version). Unlike other emissions in this study, no log-transformation was applied to the CBFE data as the distribution of points generally falls within a narrow band defined by the vehicle efficiency and test cycle energy requirement.

The SAS Mixed procedure was used with the restricted maximum likelihood (REML) method in an initial round of model fitting to examine the behavior of residuals and assess the effect of generating covariance parameters specific to each vehicle. In Figure A2.4, conditional studentized residuals have a somewhat narrow distribution with notable extension of the upper tail. Figure A2.5 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for "outlier points". Results indicate all points fall within the acceptable range.

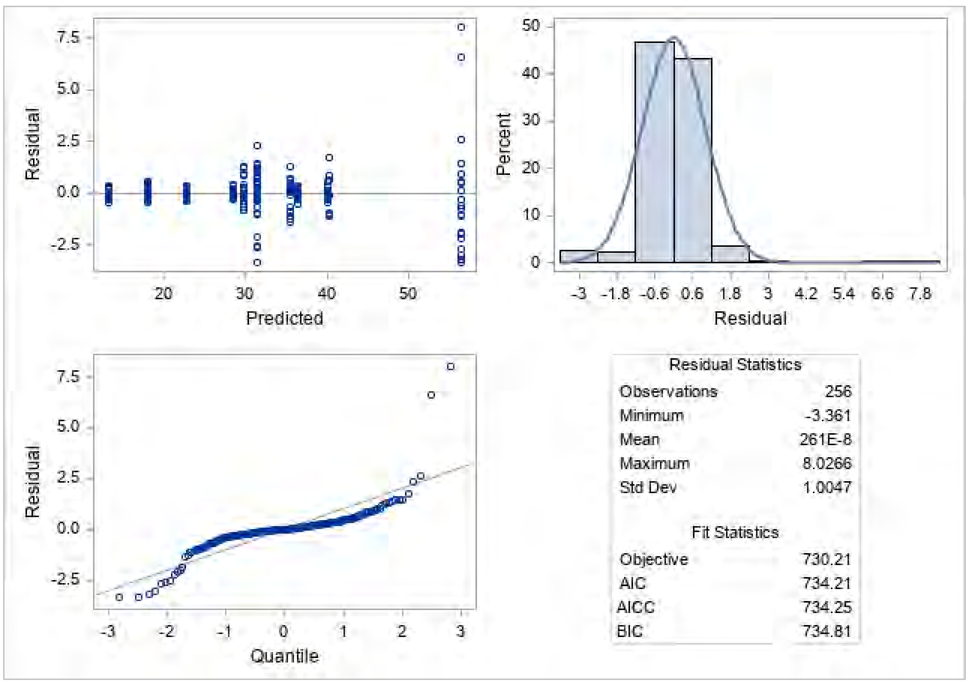

Figure A2.4. Analysis of conditional studentized residuals for FTP cycle CBFE data.

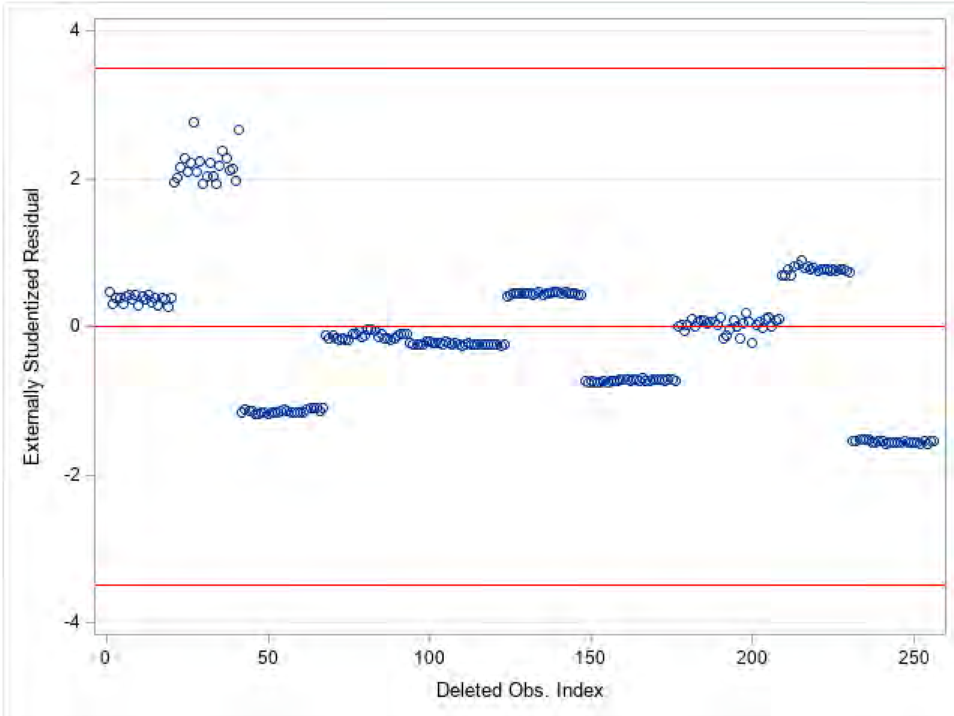

Figure A2.5. Externally studentized residuals for FTP cycle CBFE data.

Following this initial analysis, the model was refit using the maximum likelihood method to generate the intercept and fixed effect coefficient for the PMI fuel term. The model parameters and related fit statistics are presented in Table A2.2. These results indicate that PMI is not a significant predictor of CBFE in the FTP cycle.

Table A2.2. PMI model parameters for FTP CBFE.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	31.1012	3.6644	10	8.49	<.0001
PMI	0.0374	0.0906	246	0.41	0.6804

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table A2.3 presents differences of least squares means for fuel pairs.

Table A2.3. Differences in least squares means by fuel for FTP CBFE.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adj P
A	**B**	0.0313	0.1547	246	0.2	0.9996
A	**C**	0.0425	0.1568	246	0.27	0.9988
A	**D**	-0.0492	0.1526	246	-0.32	0.9977
A	**Base**	0.2921	0.1933	246	1.51	0.5562
B	**C**	0.0112	0.1798	246	0.06	1.0000
B	**D**	-0.0805	0.1762	246	-0.46	0.9910
B	**Base**	0.2608	0.2130	246	1.22	0.7372
C	**D**	-0.0917	0.1780	246	-0.52	0.9858
C	**Base**	0.2496	0.2146	246	1.16	0.7726
D	**Base**	0.3412	0.2114	246	1.61	0.4898

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results show no statistically significant differences between any fuels.

US06 Cycle Data

Figure A2.6 provides a graphical overview of carbon-balance fuel economy (CBFE) measurements collected on the US06 cycle, grouped by vehicle. The axis label "index" refers to the count of individual observations. Vehicle means fall between roughly 14 and 36 MPG.

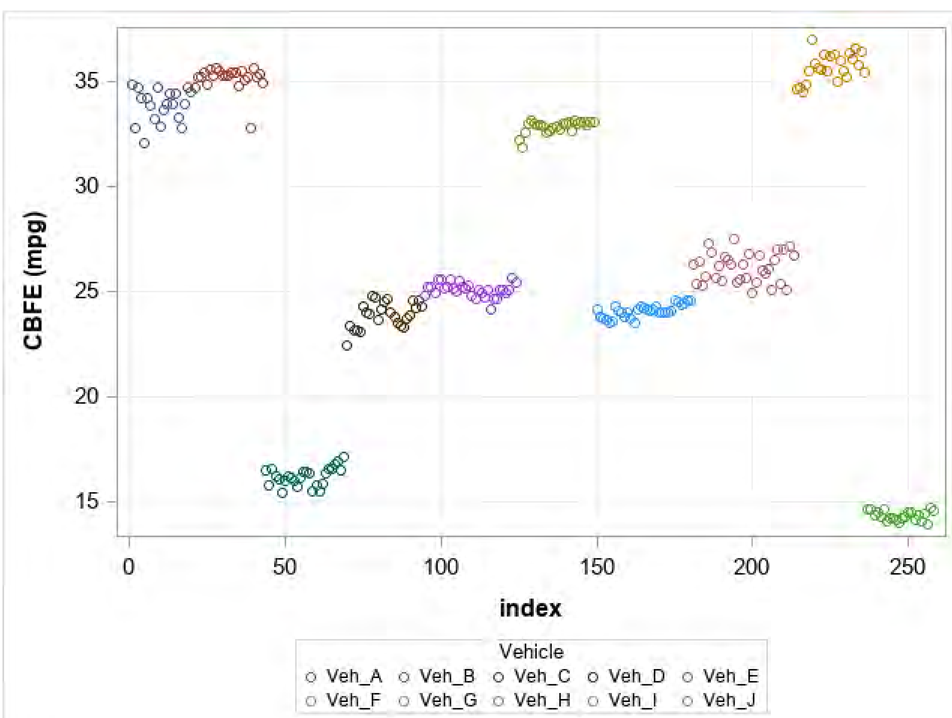

Figure A2.6. US06 CBFE dataset used in the analysis.

Figure A2.7 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure A2.8 presents vehicle means by PM Index. Table A2.4 summarizes the number of measurements collected and analyzed for each vehicle.

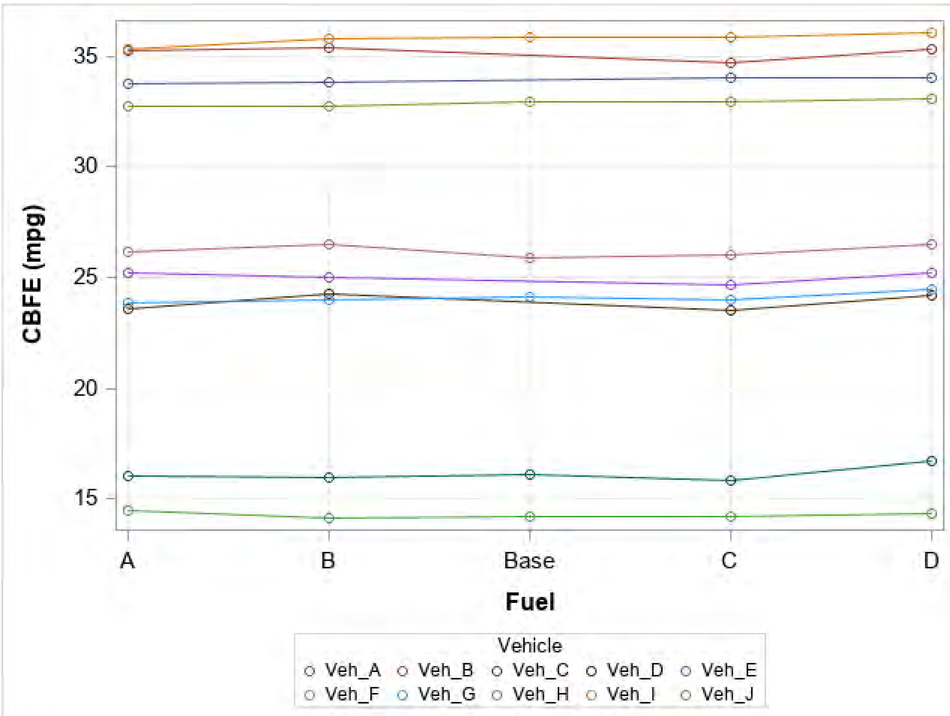

Figure A2.7. US06 CBFE data as vehicle means by fuel.

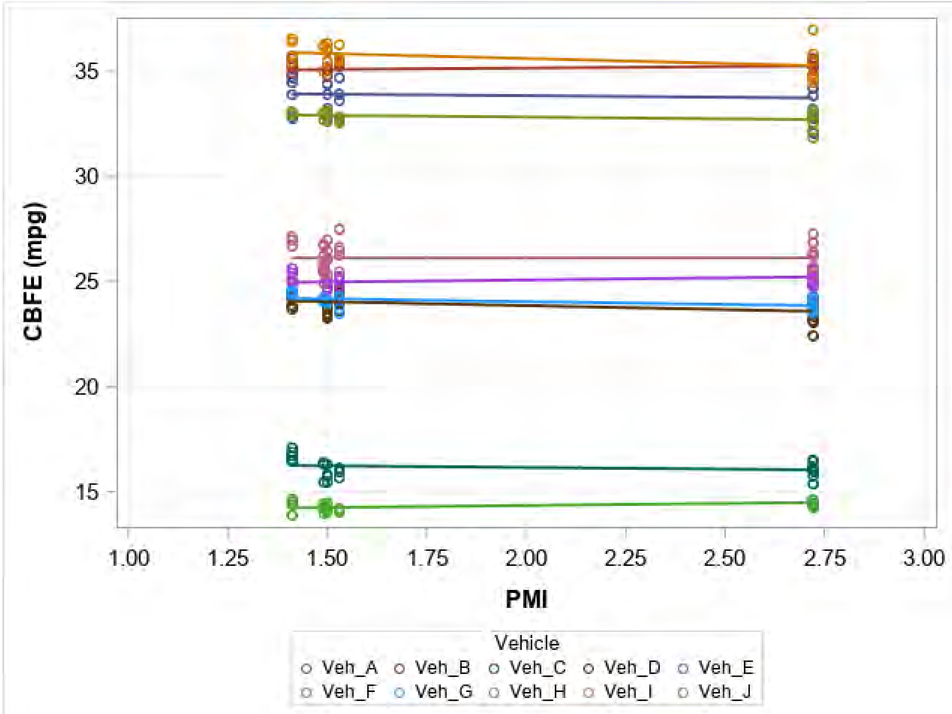

Figure A2.8. US06 CBFE data as vehicle means by PM Index.

Table A2.4. Number of CBFE measurements collected and analyzed in the US06 cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	23	26	25	30	25	31	33	23	22	258

Data analysis and model fitting proceeded in the same manner as for the FTP cycle as described above. Figure A2.9 indicates conditional studentized residuals are approximately normally distributed with some deviation toward the lower tail. Figure A2.10 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points fall well within the acceptable range.

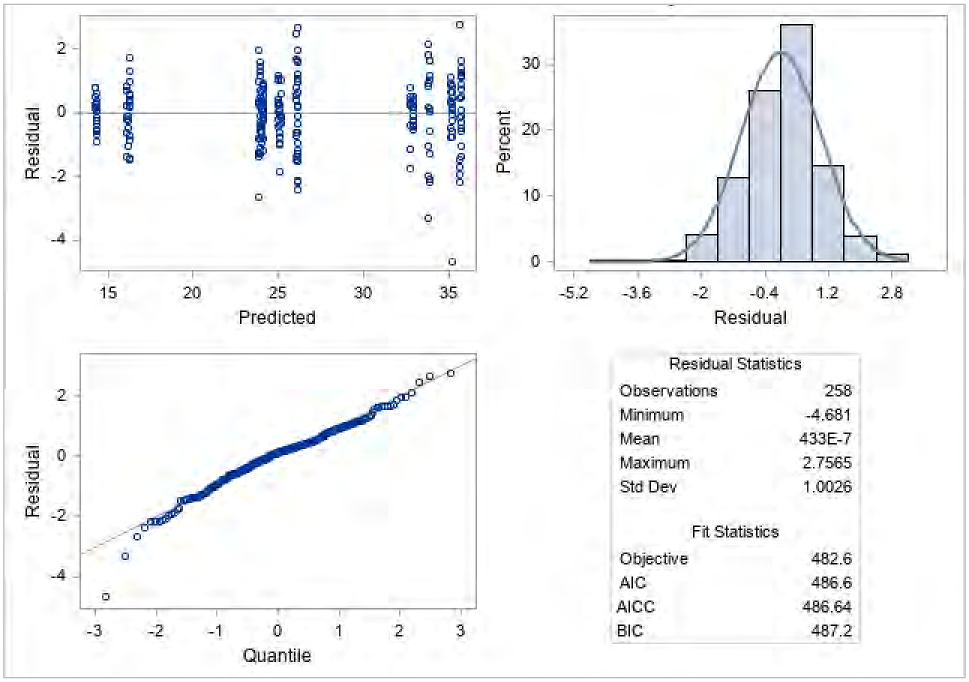

Figure A2.9. Analysis of conditional studentized residuals for US06 cycle CBFE data.

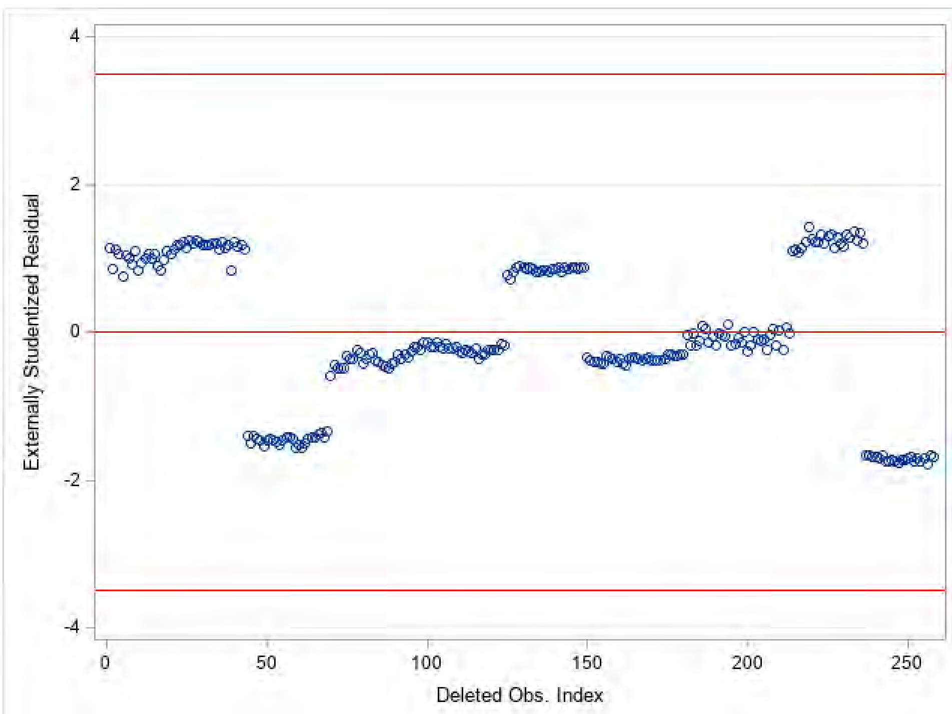

Figure A2.10. Externally studentized residuals for US06 cycle CBFE data.

The solution for fixed effects for the PMI fuel parameter model is presented in Table A2.5. These results indicate that PMI is not a significant predictor of CBFE in the US06 cycle at the $p \leq 0.05$ level.

Table A2.5. Fixed effect model parameters for US06 CBFE.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	26.9158	2.2920	10	11.74	<.0001
PMI	-0.1012	0.0555	248	-1.82	0.0696

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table A2.6 presents differences of least squares means for fuel pairs.

Table A2.6. Differences in least squares means by fuel for US06 CBFE.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adj P
A	**B**	-0.1213	0.0912	248	-1.33	0.6727
A	**C**	0.0804	0.0919	248	0.88	0.9058
A	**D**	-0.3513	0.0907	248	-3.87	0.0013
A	**Base**	0.0081	0.1132	248	0.07	1.0000
B	**C**	0.2018	0.1047	248	1.93	0.3060
B	**D**	-0.2300	0.1036	248	-2.22	0.1762
B	**Base**	0.1294	0.1240	248	1.04	0.8346
C	**D**	-0.4317	0.1043	248	-4.14	0.0005
C	**Base**	-0.0724	0.1240	248	-0.58	0.9774
D	**Base**	0.3594	0.1235	248	2.91	0.0319

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results indicate that the largest differences occurred between Fuel D and the other fuels.

A3. Inertial Work Rating

FTP Cycle Data

Figure A3.1 provides a graphical overview of inertial work rating (IWR) values generated over the FTP cycle, grouped by vehicle. IWR is one of the SAE Drive Quality Metrics (DQMs) that are used evaluate conformity between the actual and target drive speeds for chassis dynamometer tests. Statistical analysis of DQMs can provide an indication of the influence of variation in vehicle operation on the study results. The axis label “index” refers to the count of individual observations.

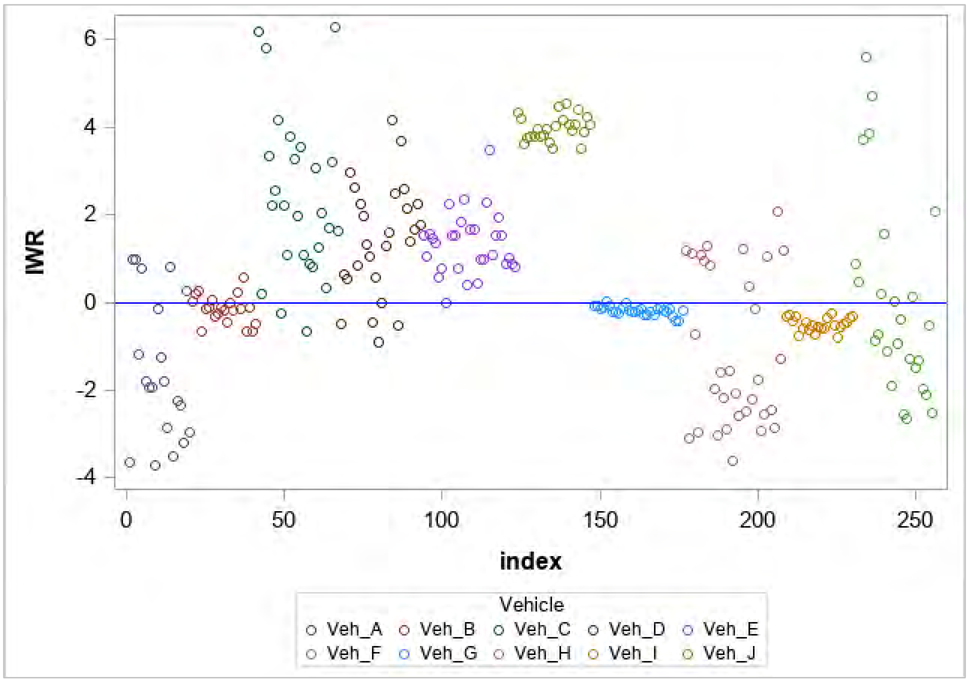

Figure A3.1. FTP IWR dataset by vehicle.

Figure A3.2 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel) and Figure A3.3 shows vehicle means by PM Index. Table A3.1 summarizes the number of measurements collected and analyzed for each vehicle.

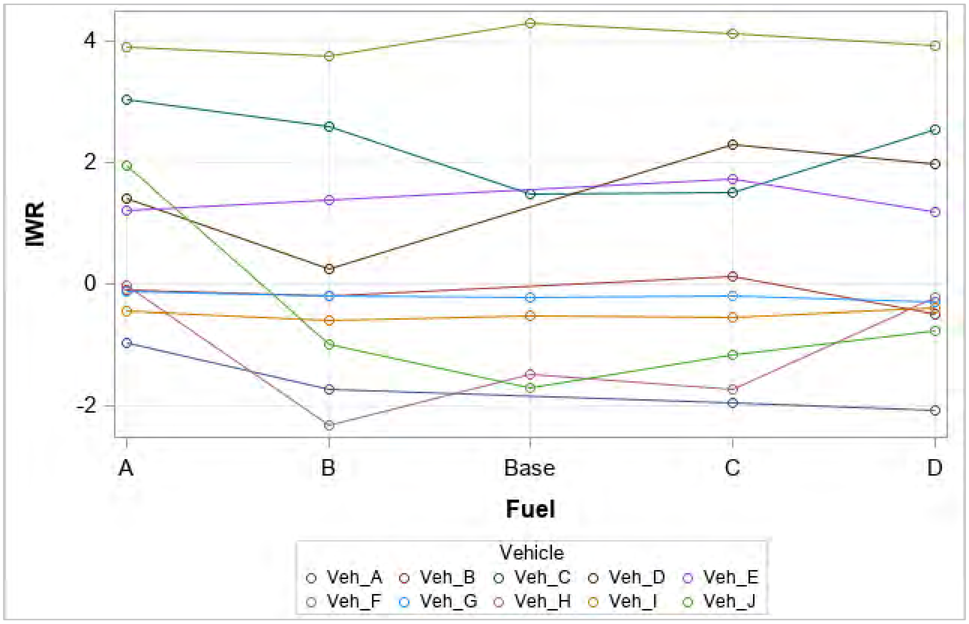

Figure A3.2. FTP IWR data as vehicle means by fuel.

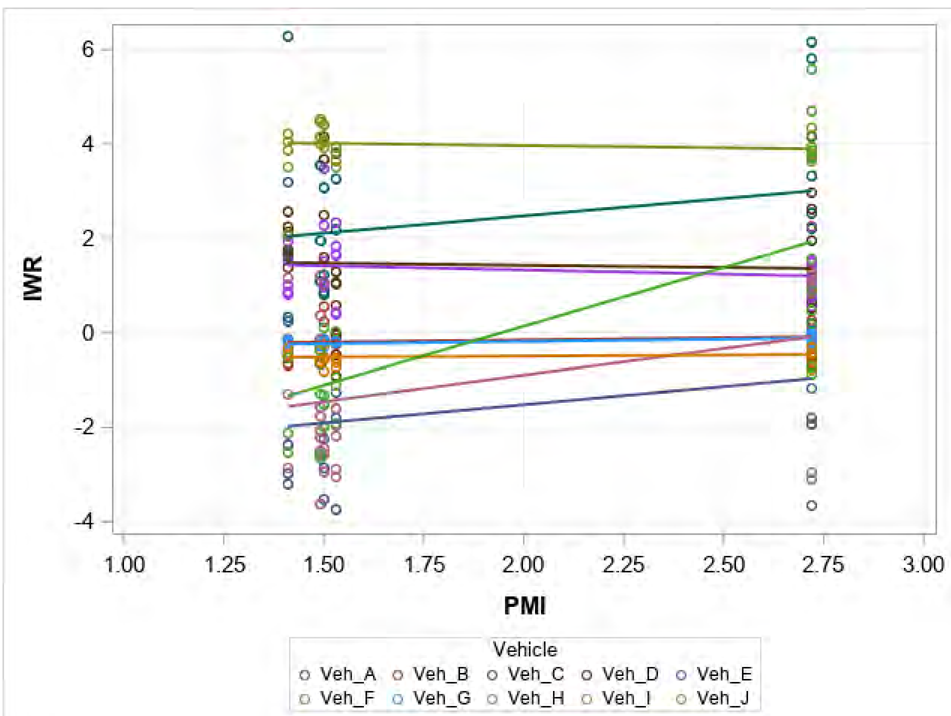

Figure A3.3. FTP IWR data as vehicle means by PM Index.

Table A3.1. Number of IWR measurements collected and analyzed in the FTP cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	21	26	26	30	24	29	32	22	26	256

Data analysis was performed using the SAS software package (current version). No log-transformation was applied to the IWR data before analysis.

The SAS Mixed procedure was used with the restricted maximum likelihood (REML) method in an initial round of model fitting to examine the behavior of residuals and assess the effect of generating covariance parameters specific to each vehicle. Figure A3.4 indicates conditional studentized residuals are approximately normally distributed with minimal deviation at the tails. Figure A3.5 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points fall well within the acceptable range.

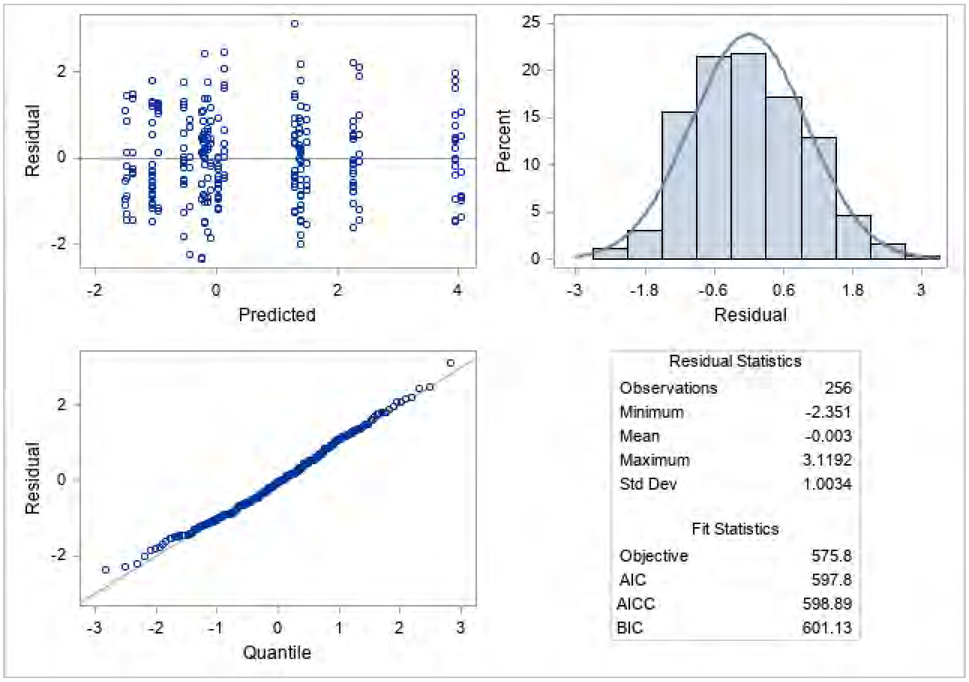

Figure A3.4. Analysis of conditional studentized residuals for FTP cycle IWR data.

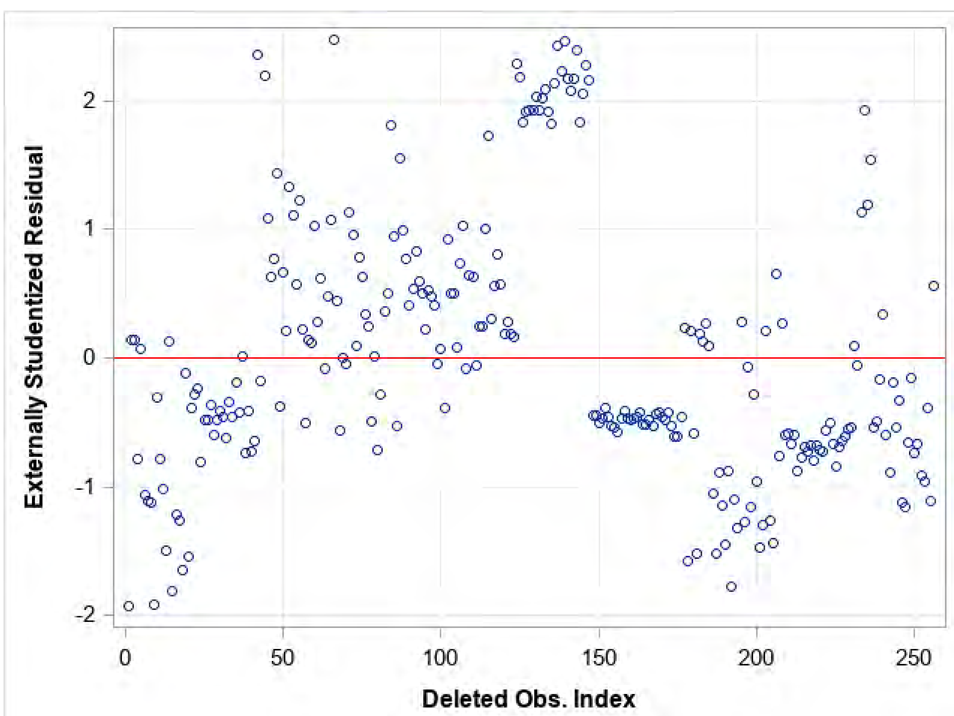

Figure A3.5. Externally studentized residuals for FTP cycle IWR data.

Following this initial analysis, the model was refit using the maximum likelihood method to generate the intercept and fixed effect coefficient for the PMI fuel term. The model parameters and related fit statistics are presented in Table A3.2. These results indicate that PMI is a statistically significant predictor of IWR in the FTP cycle.

Table A3.2. PMI model parameters for FTP IWR.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	0.4217	0.5132	10.2	0.82	0.43
PMI	0.0810	0.0235	47.2	3.45	0.0012

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table A3.3 presents differences of least squares means for fuel pairs.

Table A3.3. Differences in least squares means by fuel for FTP IWR.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adj P
A	**B**	0.1129	0.0426	47.9	2.65	0.0770
A	**C**	0.0512	0.0403	43.9	1.27	0.7099
A	**D**	0.1417	0.0384	41.8	3.69	0.0055
A	**Base**	0.0793	0.0485	43.7	1.63	0.4840
B	**C**	-0.0618	0.0489	48	-1.26	0.7154
B	**D**	0.0287	0.0474	46.6	0.61	0.9735
B	**Base**	-0.0337	0.0559	46.7	-0.6	0.9741
C	**D**	0.0905	0.0453	43.4	2	0.2852
C	**Base**	0.0281	0.0542	44.5	0.52	0.9850
D	**Base**	-0.0624	0.0528	43.4	-1.18	0.7610

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. Results show one significant difference for Fuel A vs D at the $p \leq 0.05$ level.

US06 Cycle Data

Figure A3.6 provides a graphical overview of IWR measurements collected on the US06 cycle, grouped by vehicle. The axis label “index” refers to the count of individual observations.

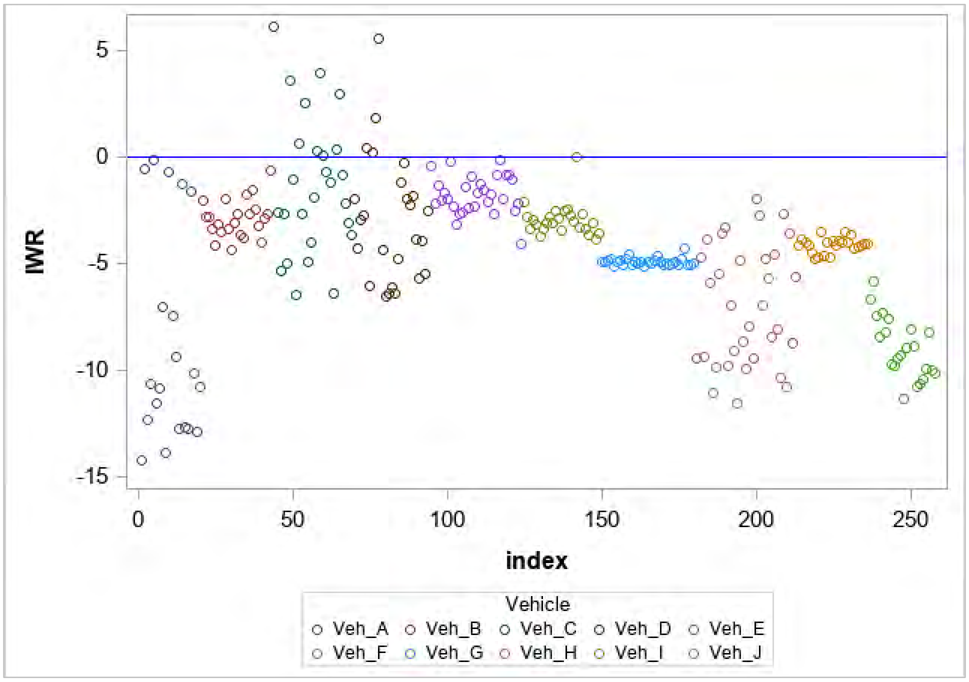

Figure A3.6. US06 IWR dataset used in the analysis.

Figure A3.7 plots the data as vehicle means by fuel (four of the vehicles did not test Base Fuel). Figure A3.8 presents vehicle means by PM Index. Table A3.4 summarizes the number of measurements collected and analyzed for each vehicle.

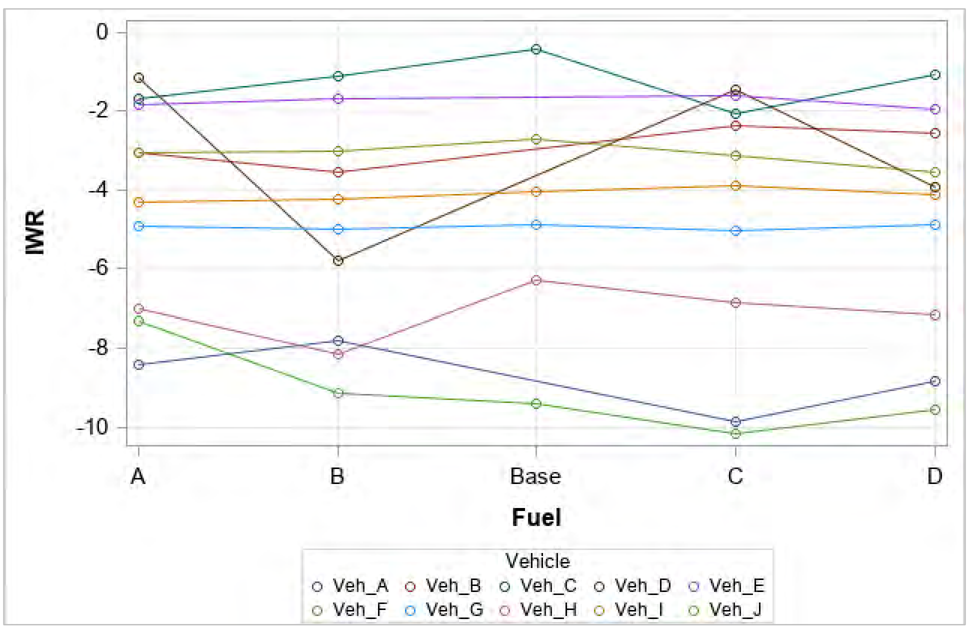

Figure A3.7. US06 IWR data as vehicle means by fuel.

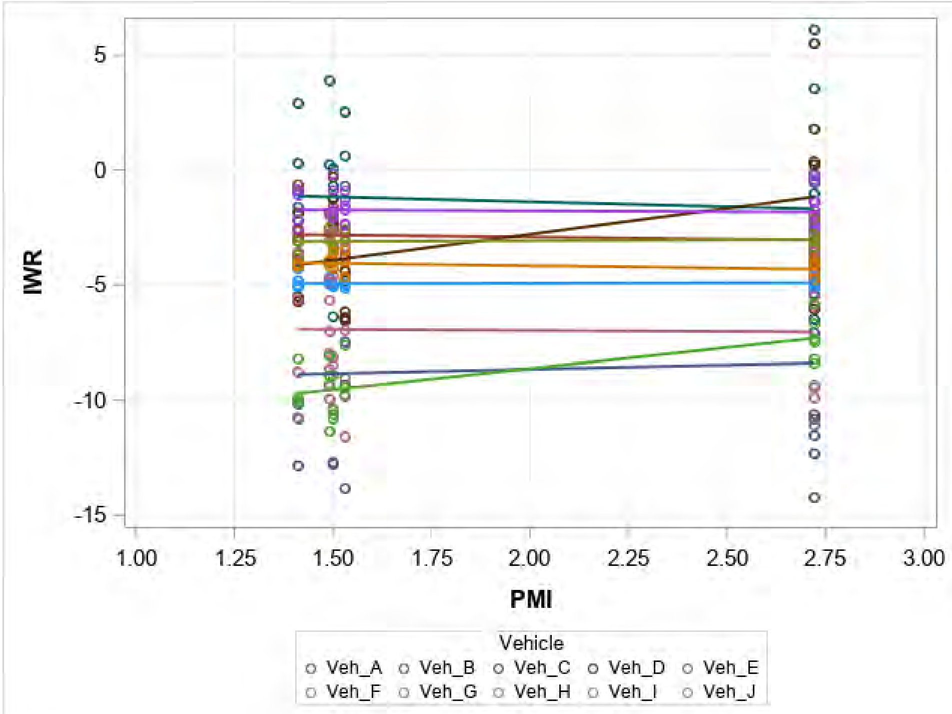

Figure A3.8. US06 IWR data as vehicle means by PM Index.

Table A3.4. Number of IWR measurements collected and analyzed in the US06 cycle model fitting.

Veh_A	Veh_B	Veh_C	Veh_D	Veh_E	Veh_F	Veh_G	Veh_H	Veh_I	Veh_J	Total
20	23	26	25	30	24	31	33	23	22	257

Data analysis and model fitting proceeded in the same manner as for the FTP cycle as described above. Figure A3.9 indicates conditional studentized residuals are approximately normally distributed with some deviations toward the tails. Figure A3.10 shows the range of externally studentized residuals, where levels of ± 3.5 are commonly used as a screen for “outlier points”. Results indicate all points fall within the acceptable range.

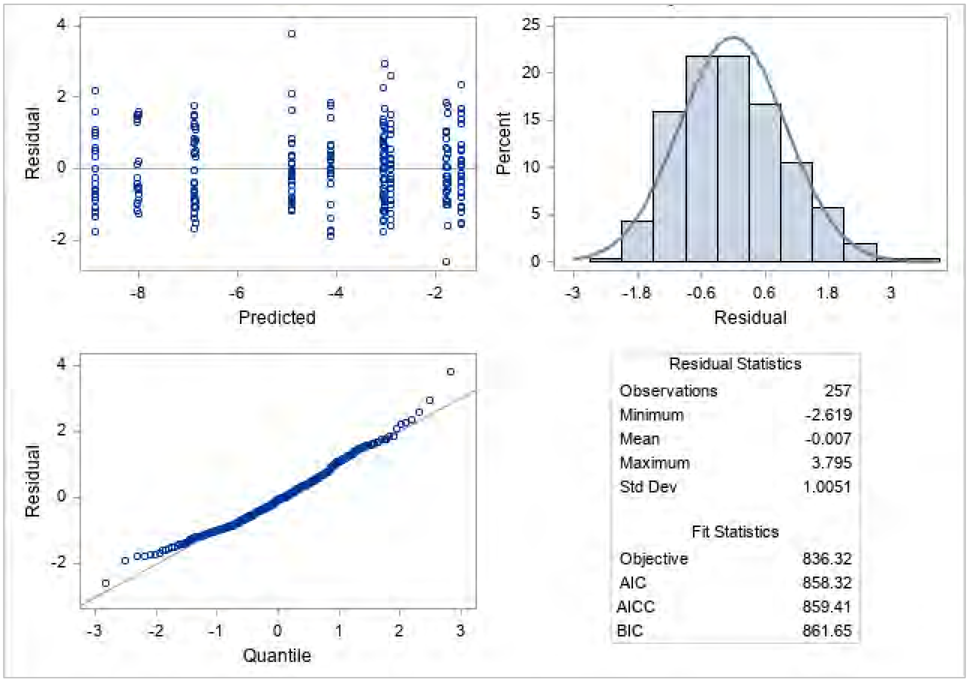

Figure A3.9. Analysis of conditional studentized residuals for US06 cycle IWR data.

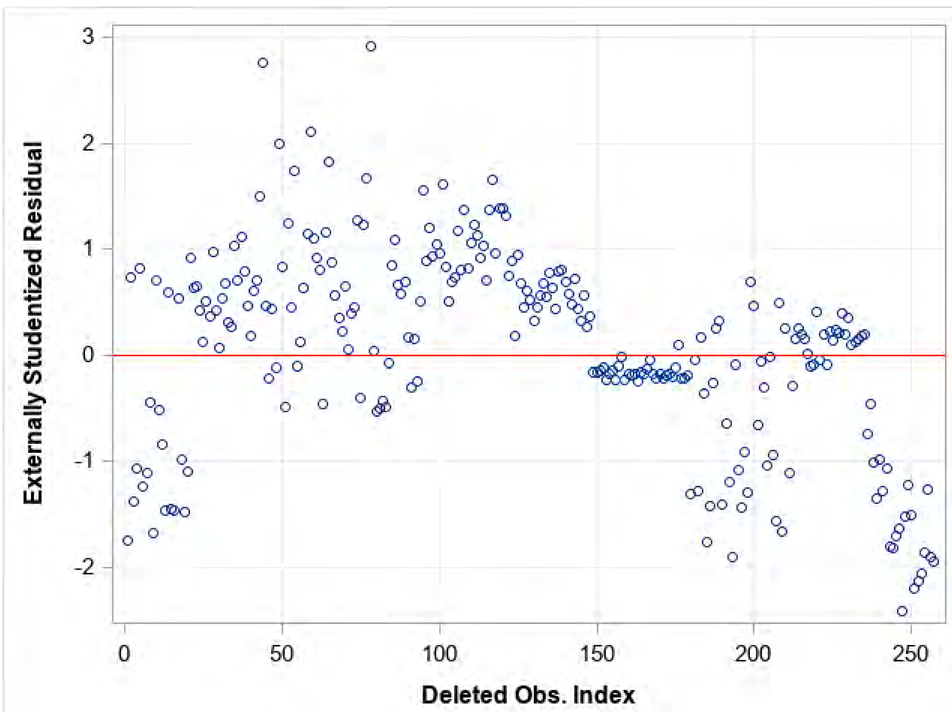

Figure A3.10. Externally studentized residuals for US06 cycle IWR data.

The solution for fixed effects for the PMI fuel parameter model is presented in Table A3.5. These results indicate that PMI is a not significant predictor of IWR in the US06.

Table A3.5. Fixed effect model parameters for US06 IWR.

Effect	Parameter Estimate	Standard Error	DF	t Value	Pr > |t|
Intercept	-4.5329	0.8083	9.73	-5.61	0.0002
PMI	0.0090	0.0462	53.4	0.2	0.8455

In addition, a mixed-factor ANOVA analysis was conducted to provide comparisons among the test fuels. Table A3.6 presents differences of least squares means for fuel pairs.

Table A3.6. Differences in least squares means by fuel for US06 IWR.

Fuel1	Fuel2	Parameter Estimate	Standard Error	DF	t Value	Adj P
A	**B**	0.0833	0.0804	51.6	1.04	0.8377
A	**C**	0.0270	0.0803	51.6	0.34	0.9972
A	**D**	0.0153	0.0768	48.5	0.2	0.9996
A	**Base**	-0.0982	0.0883	48.1	-1.11	0.7993
B	**C**	-0.0563	0.0937	52.7	-0.6	0.9743
B	**D**	-0.0680	0.0908	50.4	-0.75	0.9437
B	**Base**	-0.1815	0.1007	49.7	-1.8	0.3839
C	**D**	-0.0117	0.0907	50.4	-0.13	0.9999
C	**Base**	-0.1252	0.1006	49.7	-1.24	0.7259
D	**Base**	-0.1135	0.0978	47.8	-1.16	0.7737

Differences are interpreted as Fuel1 relative to Fuel2. Adjusted P values use the Tukey-Kramer adjustment for multiple comparisons. These results show no significant differences between any fuels.

Appendix B:
Emissions Dataset

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_A	FTP	A	2.72	-3.6542	0.0039	0.1047	0.0057	241.1	0.0030	0.0032	0.0010	36.43	2.373
Veh_A	FTP	A	2.72	0.9641	0.0042	0.1473	0.0050	254.2	0.0033	0.0036	0.0011	34.54	2.568
Veh_A	FTP	A	2.72	0.9643	0.0041	0.1323	0.0059	246.8	0.0030	0.0032	0.0013	35.59	2.366
Veh_A	FTP	A	2.72	-1.1709	0.0048	0.1448	0.0075	246.6	0.0034	0.0037	0.0016	35.61	2.408
Veh_A	FTP	A	2.72	0.7854	0.0042	0.1393	0.0091	253.7	0.0031	0.0034	0.0014	34.62	2.317
Veh_A	FTP	A	2.72	-1.7965	0.0044	0.1319	0.0068	244.9	0.0032	0.0036	0.0013	35.86	2.084
Veh_A	FTP	A	2.72	-1.9190	0.0045	0.1351	0.0070	244.6	0.0031	0.0033	0.0016	35.91	2.268
Veh_A	FTP	A	2.72	-1.9350	0.0049	0.1398	0.0068	249.1	0.0030	0.0033	0.0020	35.25	2.250
Veh_A	FTP	B	1.53	-3.7279	0.0046	0.1343	0.0067	244.1	0.0030	0.0033	0.0018	35.83	1.733
Veh_A	FTP	B	1.53	-0.1576	0.0040	0.1045	0.0065	254.7	0.0030	0.0033	0.0012	34.35	1.775
Veh_A	FTP	B	1.53	-1.2564	0.0041	0.1028	0.0062	245.4	0.0030	0.0033	0.0013	35.66	1.881
Veh_A	FTP	B	1.53	-1.7929	0.0047	0.1310	0.0069	247.8	0.0034	0.0037	0.0015	35.31	2.005
Veh_A	FTP	C	1.50	-2.8549	0.0049	0.1383	0.0058	240.7	0.0032	0.0035	0.0019	35.89	1.545
Veh_A	FTP	C	1.50	0.8187	0.0043	0.1532	0.0060	248.7	0.0091	0.0100	0.0015	34.74	1.583
Veh_A	FTP	C	1.50	-3.5230	0.0046	0.1113	0.0070	243.0	0.0034	0.0037	0.0014	35.56	1.189
Veh_A	FTP	C	1.50	-2.2321	0.0043	0.1029	0.0073	252.4	0.0034	0.0037	0.0013	34.24	1.313
Veh_A	FTP	D	1.41	-2.3551	0.0041	0.1155	0.0057	243.0	0.0032	0.0036	0.0012	35.56	1.435
Veh_A	FTP	D	1.41	-3.1940	0.0037	0.0941	0.0066	244.5	0.0028	0.0032	0.0011	35.35	1.423
Veh_A	FTP	D	1.41	0.2581	0.0045	0.1394	0.0059	253.2	0.0034	0.0039	0.0013	34.12	1.258
Veh_A	FTP	D	1.41	-2.9681	0.0045	0.1156	0.0065	244.4	0.0033	0.0038	0.0013	35.36	1.477
Veh_A	US06	A	2.72	-14.2270	0.0064	0.0805	0.0040	252.0	0.0107	0.0110	0.0000	34.87	1.079
Veh_A	US06	A	2.72	-0.5396	0.0056	0.4365	0.0042	267.5	0.0058	0.0059	0.0001	32.78	1.344
Veh_A	US06	A	2.72	-12.3117	0.0054	0.1699	0.0045	252.9	0.0101	0.0104	0.0000	34.72	1.002
Veh_A	US06	A	2.72	-10.6040	0.0047	0.4933	0.0033	255.8	0.0048	0.0050	0.0001	34.26	1.270
Veh_A	US06	A	2.72	-0.1346	0.0069	0.7817	0.0043	272.6	0.0067	0.0069	0.0002	32.10	0.658
Veh_A	US06	A	2.72	-11.5300	0.0068	0.1123	0.0039	256.7	0.0066	0.0068	0.0002	34.22	0.546
Veh_A	US06	A	2.72	-10.8184	0.0052	0.2566	0.0042	259.1	0.0051	0.0053	0.0001	33.87	0.719
Veh_A	US06	A	2.72	-7.0620	0.0038	0.0968	0.0035	264.2	0.0037	0.0039	0.0001	33.25	0.684
Veh_A	US06	B	1.53	-13.8354	0.0042	0.0887	0.0035	251.9	0.0044	0.0046	0.0000	34.74	0.522
Veh_A	US06	B	1.53	-0.6968	0.0051	0.4876	0.0035	265.8	0.0053	0.0055	0.0000	32.84	0.801
Veh_A	US06	B	1.53	-7.4522	0.0041	0.1931	0.0035	260.1	0.0044	0.0046	0.0000	33.62	0.437
Veh_A	US06	B	1.53	-9.3296	0.0035	0.2129	0.0040	257.4	0.0038	0.0039	0.0000	33.97	0.692
Veh_A	US06	C	1.50	-12.7264	0.0050	0.1322	0.0031	250.9	0.0051	0.0053	0.0001	34.44	0.419

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_A	US06	C	1.50	-1.2663	0.0053	0.6598	0.0045	253.8	0.0054	0.0055	0.0000	33.92	0.899
Veh_A	US06	C	1.50	-12.6864	0.0058	0.1398	0.0035	252.4	0.0059	0.0061	0.0001	34.42	0.351
Veh_A	US06	C	1.50	-12.7376	0.0043	0.1698	0.0035	261.1	0.0045	0.0046	0.0043	33.26	0.388
Veh_A	US06	D	1.41	-10.1492	0.0040	0.1642	0.0033	254.7	0.0042	0.0043	0.0001	33.92	0.654
Veh_A	US06	D	1.41	-1.6125	0.0057	0.4718	0.0046	262.8	0.0058	0.0060	0.0001	32.81	0.806
Veh_A	US06	D	1.41	-12.8400	0.0059	0.0669	0.0042	248.7	0.0063	0.0064	0.0000	34.76	0.403
Veh_A	US06	D	1.41	-10.7722	0.0035	0.1655	0.0037	250.4	0.0035	0.0036	0.0001	34.50	0.339
Veh_B	FTP	D	1.41	-0.6701	0.0113	0.0341	0.0044	162.6	0.0090	0.0103	0.0023	55.77	0.196
Veh_B	FTP	A	2.72	-0.6655	0.0122	0.0385	0.0013	160.5	0.0101	0.0110	0.0021	57.61	0.252
Veh_B	FTP	D	1.41	-0.6501	0.0109	0.0278	0.0019	165.7	0.0087	0.0099	0.0022	54.13	0.202
Veh_B	FTP	D	1.41	-0.5110	0.0109	0.0363	0.0027	155.1	0.0086	0.0098	0.0023	61.88	0.232
Veh_B	FTP	B	1.53	-0.4632	0.0128	0.0423	0.0021	162.9	0.0104	0.0114	0.0024	56.81	0.094
Veh_B	FTP	A	2.72	-0.3227	0.0133	0.0448	0.0015	165.1	0.0110	0.0121	0.0023	55.57	0.272
Veh_B	FTP	B	1.53	-0.2416	0.0115	0.0428	0.0019	161.0	0.0096	0.0105	0.0019	57.14	0.147
Veh_B	FTP	B	1.53	-0.1959	0.0125	0.0443	0.0023	165.9	0.0103	0.0113	0.0022	54.69	0.101
Veh_B	FTP	C	1.50	-0.1911	0.0115	0.0306	0.0026	168.9	0.0094	0.0103	0.0021	53.55	0.194
Veh_B	FTP	A	2.72	-0.1490	0.0148	0.0584	0.0018	166.2	0.0123	0.0134	0.0025	55.47	0.286
Veh_B	FTP	C	1.50	-0.1363	0.0113	0.0344	0.0019	159.4	0.0093	0.0102	0.0020	58.56	0.111
Veh_B	FTP	A	2.72	-0.1319	0.0140	0.0473	0.0085	162.8	0.0117	0.0128	0.0024	56.84	0.206
Veh_B	FTP	D	1.41	-0.1305	0.0117	0.0280	0.0029	162.3	0.0092	0.0105	0.0024	55.84	0.234
Veh_B	FTP	B	1.53	-0.1222	0.0128	0.0419	0.0025	167.0	0.0106	0.0116	0.0022	53.69	0.140
Veh_B	FTP	B	1.53	-0.0050	0.0156	0.0592	0.0023	166.4	0.0133	0.0146	0.0023	54.80	0.134
Veh_B	FTP	A	2.72	0.0081	0.0141	0.0563	0.0035	169.7	0.0118	0.0129	0.0023	53.89	0.339
Veh_B	FTP	A	2.72	0.0442	0.0136	0.0453	0.0021	156.2	0.0117	0.0128	0.0020	63.11	0.392
Veh_B	FTP	A	2.72	0.1750	0.0109	0.0296	0.0025	166.7	0.0088	0.0097	0.0020	54.57	0.287
Veh_B	FTP	C	1.50	0.2358	0.0115	0.0542	0.0023	163.1	0.0095	0.0104	0.0020	56.47	0.238
Veh_B	FTP	A	2.72	0.2661	0.0120	0.0433	0.0014	164.3	0.0097	0.0106	0.0023	56.13	0.318
Veh_B	FTP	C	1.50	0.5591	0.0131	0.0526	0.0025	161.9	0.0107	0.0117	0.0024	57.58	0.138
Veh_B	US06	A	2.72	-2.0674	0.0148	0.1168	0.0069	251.5	0.0127	0.0131	0.0021	34.70	0.377
Veh_B	US06	A	2.72	-2.8128	0.0108	0.1338	0.0062	247.7	0.0092	0.0095	0.0016	35.26	0.364
Veh_B	US06	A	2.72	-2.7915	0.0106	0.1236	0.0064	247.8	0.0089	0.0091	0.0018	35.26	0.280
Veh_B	US06	A	2.72	-3.4037	0.0108	0.0772	0.0061	247.3	0.0088	0.0091	0.0020	35.41	0.320
Veh_B	US06	A	2.72	-4.1688	0.0089	0.0966	0.0060	250.6	0.0075	0.0077	0.0015	34.84	0.211

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_B	US06	A	2.72	-3.1561	0.0086	0.0601	0.0047	245.8	0.0072	0.0074	0.0015	35.56	0.221
Veh_B	US06	A	2.72	-3.5419	0.0081	0.0853	0.0054	247.6	0.0066	0.0068	0.0015	35.27	0.188
Veh_B	US06	A	2.72	-1.9445	0.0160	0.2352	0.0054	245.2	0.0139	0.0143	0.0021	35.66	0.227
Veh_B	US06	A	2.72	-3.4042	0.0186	0.1449	0.0051	245.7	0.0165	0.0170	0.0021	35.54	0.178
Veh_B	US06	B	1.53	-4.3472	0.0083	0.0561	0.0054	246.6	0.0068	0.0070	0.0015	35.30	0.206
Veh_B	US06	B	1.53	-3.1039	0.0080	0.0612	0.0048	246.7	0.0063	0.0065	0.0017	35.30	0.345
Veh_B	US06	B	1.53	-2.7072	0.0063	0.0374	0.0045	247.2	0.0050	0.0052	0.0013	35.31	0.242
Veh_B	US06	B	1.53	-3.6977	0.0088	0.0718	0.0039	246.2	0.0072	0.0074	0.0016	35.44	0.184
Veh_B	US06	B	1.53	-3.8261	0.0066	0.0313	0.0062	246.3	0.0052	0.0053	0.0014	35.45	0.065
Veh_B	US06	C	1.50	-1.7980	0.0093	0.0867	0.0028	249.1	0.0075	0.0077	0.0018	34.83	0.171
Veh_B	US06	C	1.50	-2.6628	0.0089	0.0905	0.0044	243.8	0.0074	0.0076	0.0016	35.54	
Veh_B	US06	C	1.50	-1.5753	0.0111	0.2018	0.0050	247.5	0.0092	0.0094	0.0020	35.08	0.169
Veh_B	US06	C	1.50	-2.4368	0.0120	0.0950	0.0066	246.4	0.0100	0.0104	0.0019	35.25	0.156
Veh_B	US06	C	1.50	-3.2767	0.0178	0.1929	0.0055	264.0	0.0153	0.0157	0.0025	32.83	0.263
Veh_B	US06	D	1.41	-4.0494	0.0081	0.0530	0.0039	242.2	0.0066	0.0068	0.0015	35.65	0.309
Veh_B	US06	D	1.41	-2.9170	0.0104	0.1005	0.0073	245.1	0.0087	0.0089	0.0018	35.20	0.551
Veh_B	US06	D	1.41	-2.6491	0.0067	0.0359	0.0030	243.8	0.0053	0.0054	0.0014	35.36	0.179
Veh_B	US06	D	1.41	-0.6324	0.0050	0.0406	0.0057	247.4	0.0037	0.0038	0.0013	34.93	0.245
Veh_C	FTP	A	2.72	6.1734	0.0369	0.1367	0.0306	487.8	0.0258	0.0283	0.0120	17.86	8.100
Veh_C	FTP	A	2.72	0.2027	0.0401	0.2675	0.0191	478.7	0.0271	0.0297	0.0141	18.20	8.200
Veh_C	FTP	A	2.72	5.8207	0.0522	0.3557	0.0142	486.2	0.0388	0.0425	0.0153	17.91	10.130
Veh_C	FTP	A	2.72	3.3338	0.0433	0.3588	0.0222	486.0	0.0301	0.0330	0.0142	17.92	9.200
Veh_C	FTP	A	2.72	2.2118	0.0508	0.2433	0.0194	494.9	0.0354	0.0388	0.0167	17.60	8.546
Veh_C	FTP	A	2.72	2.5501	0.0398	0.2146	0.0143	494.1	0.0255	0.0279	0.0155	17.63	8.301
Veh_C	FTP	A	2.72	4.1579	0.0424	0.2828	0.0121	490.0	0.0282	0.0309	0.0153	17.77	8.972
Veh_C	FTP	A	2.72	-0.2650	0.0391	0.2262	0.0189	491.7	0.0258	0.0283	0.0143	17.72	8.103
Veh_C	FTP	B	1.53	2.1983	0.0377	0.2589	0.0231	498.0	0.0255	0.0279	0.0131	17.50	5.469
Veh_C	FTP	B	1.53	1.0656	0.0391	0.1898	0.0210	494.9	0.0268	0.0294	0.0132	17.61	6.077
Veh_C	FTP	B	1.53	3.8029	0.0417	0.2531	0.0444	490.0	0.0287	0.0315	0.0141	17.78	5.767
Veh_C	FTP	B	1.53	3.2705	0.0349	0.2185	0.0344	492.9	0.0222	0.0243	0.0138	17.68	6.728
Veh_C	FTP	Base	1.49	1.9563	0.0332	0.2033	0.0479	481.2	0.0220	0.0242	0.0121	17.98	5.446
Veh_C	FTP	Base	1.49	3.5542	0.0393	0.2252	0.0245	474.5	0.0268	0.0294	0.0136	18.23	6.121
Veh_C	FTP	Base	1.49	1.0859	0.0342	0.2298	0.0290	480.9	0.0042	0.0046	0.0101	17.99	5.216

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_C	FTP	Base	1.49	-0.6617	0.0443	0.2466	0.0286	486.0	0.0297	0.0326	0.0158	17.80	5.560
Veh_C	FTP	C	1.50	0.8746	0.0343	0.2855	0.0236	487.7	0.0225	0.0247	0.0128	17.72	5.664
Veh_C	FTP	C	1.50	0.8156	0.0483	0.3074	0.0143	485.4	0.0341	0.0374	0.0154	17.80	5.511
Veh_C	FTP	C	1.50	3.0836	0.0351	0.2583	0.0120	486.9	0.0227	0.0249	0.0134	17.75	5.444
Veh_C	FTP	C	1.50	1.2354	0.0352	0.2425	0.0377	486.2	0.0229	0.0251	0.0135	17.77	5.265
Veh_C	FTP	D	1.41	2.0575	0.0377	0.2435	0.0441	474.3	0.0256	0.0291	0.0132	18.09	
Veh_C	FTP	D	1.41	0.3299	0.0398	0.2141	0.0418	470.0	0.0261	0.0296	0.0146	18.26	5.200
Veh_C	FTP	D	1.41	1.7103	0.0404	0.2555	0.0282	468.1	0.0281	0.0319	0.0134	18.33	5.900
Veh_C	FTP	D	1.41	3.1898	0.0481	0.2720	0.0320	467.6	0.0343	0.0389	0.0150	18.35	6.700
Veh_C	FTP	D	1.41	6.2909	0.0388	0.2284	0.0310	480.6	0.0276	0.0313	0.0122	17.86	5.100
Veh_C	FTP	D	1.41	1.6209	0.0107	0.0957	0.0087	456.1	0.0037	0.0042	0.0076	18.29	6.000
Veh_C	US06	A	2.72	6.1100	0.0343	1.2312	0.0099	528.0	0.0223	0.0230	0.0130	16.45	5.200
Veh_C	US06	A	2.72	-2.6100	0.0257	1.9297	0.0132	549.5	0.0271	0.0279	0.0141	15.78	5.700
Veh_C	US06	A	2.72	-5.3800	0.0303	0.3557	0.0142	486.2	0.0196	0.0202	0.0116	16.53	4.500
Veh_C	US06	A	2.72	-2.6800	0.0283	1.7641	0.0107	534.8	0.0171	0.0176	0.0121	16.22	5.700
Veh_C	US06	A	2.72	-4.9700	0.0218	2.2273	0.0095	539.9	0.0127	0.0131	0.0099	16.04	5.310
Veh_C	US06	A	2.72	3.5500	0.0283	1.7209	0.0096	564.0	0.0179	0.0184	0.0155	15.38	4.598
Veh_C	US06	A	2.72	-1.0400	0.0219	1.4875	0.0104	542.5	0.0133	0.0137	0.0093	16.00	5.181
Veh_C	US06	A	2.72	-6.4700	0.0242	1.5707	0.0069	535.5	0.0144	0.0148	0.0106	16.21	4.460
Veh_C	US06	B	1.53	0.6200	0.0294	1.9781	0.0073	538.8	0.0173	0.0178	0.0131	16.09	3.132
Veh_C	US06	B	1.53	-2.6800	0.0254	1.5207	0.0076	543.6	0.0155	0.0160	0.0107	15.97	3.683
Veh_C	US06	B	1.53	2.5500	0.0306	3.8743	0.0195	550.3	0.0171	0.0176	0.0146	15.68	5.779
Veh_C	US06	B	1.53	-4.9400	0.0263	3.6763	0.0091	534.2	0.0146	0.0150	0.0127	16.15	2.916
Veh_C	US06	Base	1.49	-4.0200	0.0218	1.4534	0.0082	525.8	0.0125	0.0129	0.0100	16.39	8.307
Veh_C	US06	Base	1.49	-1.8900	0.0232	1.7900	0.0084	525.0	0.0140	0.0144	0.0103	16.40	4.065
Veh_C	US06	Base	1.49	0.2400	0.0262	1.9493	0.0093	527.0	0.0152	0.0157	0.0119	16.33	3.733
Veh_C	US06	Base	1.49	3.9100	0.0222	1.4583	0.0096	557.4	0.0124	0.0128	0.0106	15.47	4.146
Veh_C	US06	C	1.50	0.0700	0.0255	1.5123	0.0089	546.0	0.0155	0.0160	0.0109	15.77	4.310
Veh_C	US06	C	1.50	-0.6900	0.0254	2.0351	0.0101	554.9	0.0147	0.0151	0.0116	15.50	4.860
Veh_C	US06	C	1.50	-1.2000	0.0237	1.5861	0.0096	543.0	0.0138	0.0142	0.0107	15.86	4.980
Veh_C	US06	C	1.50	-6.3800	0.0231	1.3501	0.0084	528.0	0.0130	0.0134	0.0114	16.32	4.130
Veh_C	US06	D	1.41	0.3100	0.0312	1.2021	0.0126	518.1	0.0192	0.0198	0.0130	16.52	3.500
Veh_C	US06	D	1.41	2.9200	0.0306	1.4352	0.0110	517.4	0.0304	0.0313	0.0002	16.53	6.300

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_C	US06	D	1.41	-0.8700	0.0277	1.1399	0.0096	511.6	0.0166	0.0171	0.0120	16.73	3.400
Veh_C	US06	D	1.41	-2.1700	0.0271	1.1966	0.0161	506.4	0.0161	0.0166	0.0118	16.90	2.900
Veh_C	US06	D	1.41	-3.0900	0.0220	0.8232	0.0100	521.0	0.0130	0.0134	0.0098	16.45	2.900
Veh_C	US06	D	1.41	-3.6300	0.0257	1.0320	0.0102	500.3	0.0165	0.0170	0.0100	17.11	3.000
Veh_D	FTP	A	2.72	-0.5004	0.0054	0.0998	0.0132	293.3	0.0040	0.0044	0.0019	29.71	0.650
Veh_D	FTP	A	2.72	0.6442	0.0076	0.0948	0.0113	298.8	0.0061	0.0066	0.0018	29.16	0.620
Veh_D	FTP	A	2.72	0.5377	0.0059	0.1401	0.0149	291.9	0.0041	0.0045	0.0021	29.84	0.670
Veh_D	FTP	A	2.72	2.9721	0.0070	0.0964	0.0113	297.6	0.0054	0.0059	0.0018	29.28	1.160
Veh_D	FTP	A	2.72	2.6254	0.0065	0.3771	0.0124	299.6	0.0046	0.0051	0.0021	29.04	0.990
Veh_D	FTP	A	2.72	0.8295	0.0057	0.1375	0.0095	296.6	0.0043	0.0047	0.0016	29.38	0.560
Veh_D	FTP	A	2.72	2.2527	0.0067	0.1220	0.0085	300.7	0.0053	0.0058	0.0017	28.97	0.600
Veh_D	FTP	A	2.72	1.9594	0.0063	0.1541	0.0086	299.2	0.0047	0.0051	0.0019	29.12	0.840
Veh_D	FTP	A	2.72	1.3344	0.0061	0.1105	0.0095	291.3	0.0047	0.0052	0.0017	29.91	0.770
Veh_D	FTP	B	1.53	1.0525	0.0056	0.0746	0.0119	290.2	0.0041	0.0045	0.0020	30.04	0.490
Veh_D	FTP	B	1.53	-0.4700	0.0063	0.0912	0.0154	286.3	0.0045	0.0049	0.0021	30.45	0.570
Veh_D	FTP	B	1.53	0.5788	0.0060	0.0962	0.0139	297.0	0.0045	0.0049	0.0021	29.36	0.340
Veh_D	FTP	B	1.53	-0.9005	0.0063	0.0770	0.0124	292.6	0.0049	0.0054	0.0018	29.80	0.360
Veh_D	FTP	B	1.53	-0.0299	0.0056	0.1171	0.0098	283.7	0.0041	0.0045	0.0021	30.73	0.340
Veh_D	FTP	B	1.53	1.3016	0.0056	0.1285	0.0130	284.1	0.0040	0.0043	0.0022	30.68	0.370
Veh_D	FTP	C	1.50	1.5968	0.0082	0.1333	0.0122	284.3	0.0059	0.0065	0.0026	30.40	0.740
Veh_D	FTP	C	1.50	4.1644	0.0067	0.1230	0.0130	292.7	0.0048	0.0052	0.0022	29.53	0.810
Veh_D	FTP	C	1.50	2.4927	0.0061	0.1167	0.0127	289.2	0.0045	0.0049	0.0020	29.90	0.740
Veh_D	FTP	C	1.50	-0.5243	0.0072	0.0974	0.0102	289.2	0.0052	0.0057	0.0024	29.90	1.040
Veh_D	FTP	C	1.50	3.6817	0.0064	0.0964	0.0135	294.4	0.0048	0.0053	0.0019	29.36	0.720
Veh_D	FTP	D	1.41	2.5747	0.0072	0.0911	0.0108	295.5	0.0057	0.0065	0.0020	29.06	0.350
Veh_D	FTP	D	1.41	2.1399	0.0070	0.1006	0.0139	293.4	0.0054	0.0061	0.0020	29.26	0.320
Veh_D	FTP	D	1.41	1.3832	0.0059	0.0990	0.0101	289.3	0.0042	0.0048	0.0019	29.68	0.240
Veh_D	FTP	D	1.41	1.6562	0.0070	0.1067	0.0126	287.6	0.0053	0.0060	0.0022	29.86	0.330
Veh_D	FTP	D	1.41	2.2479	0.0081	0.1128	0.0122	287.7	0.0062	0.0071	0.0022	29.84	0.380
Veh_D	FTP	D	1.41	1.7661	0.0053	0.0786	0.0132	287.9	0.0037	0.0042	0.0019	29.83	0.210
Veh_D	US06	A	2.72	-1.9962	0.0079	2.5961	0.0326	384.4	0.0048	0.0050	0.0036	22.45	1.030
Veh_D	US06	A	2.72	-4.3293	0.0067	2.6572	0.0337	368.8	0.0043	0.0044	0.0028	23.38	0.820
Veh_D	US06	A	2.72	-2.9614	0.0082	4.2441	0.0330	369.8	0.0050	0.0052	0.0037	23.16	0.660

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_D	US06	A	2.72	-2.7801	0.0074	3.7692	0.0338	371.0	0.0044	0.0046	0.0035	23.13	1.080
Veh_D	US06	A	2.72	0.3842	0.0071	2.8776	0.0336	373.0	0.0045	0.0046	0.0030	23.09	0.610
Veh_D	US06	A	2.72	-6.0461	0.0049	0.7768	0.0356	357.5	0.0031	0.0032	0.0022	24.31	0.710
Veh_D	US06	A	2.72	0.2266	0.0044	0.7391	0.0345	362.5	0.0027	0.0028	0.0020	23.97	0.540
Veh_D	US06	A	2.72	1.7833	0.0053	1.5032	0.0393	361.9	0.0032	0.0033	0.0023	23.94	0.580
Veh_D	US06	A	2.72	5.5112	0.0057	0.8381	0.0357	350.1	0.0038	0.0039	0.0022	24.81	1.060
Veh_D	US06	B	1.53	-4.4002	0.0047	1.2500	0.0296	350.8	0.0026	0.0027	0.0021	24.73	0.360
Veh_D	US06	B	1.53	-6.5399	0.0059	1.7707	0.0361	366.3	0.0035	0.0036	0.0028	23.63	0.600
Veh_D	US06	B	1.53	-6.4326	0.0061	1.6687	0.0359	358.3	0.0037	0.0038	0.0028	24.17	0.820
Veh_D	US06	B	1.53	-6.1596	0.0047	0.7692	0.0354	354.5	0.0029	0.0029	0.0021	24.52	0.350
Veh_D	US06	B	1.53	-6.4103	0.0043	0.6579	0.0308	352.6	0.0027	0.0028	0.0018	24.67	0.470
Veh_D	US06	B	1.53	-4.8155	0.0051	1.2135	0.0316	361.5	0.0032	0.0033	0.0022	24.00	0.790
Veh_D	US06	C	1.50	-1.2267	0.0052	1.1945	0.0317	362.1	0.0033	0.0034	0.0023	23.77	0.580
Veh_D	US06	C	1.50	-0.3142	0.0058	1.9061	0.0296	365.1	0.0035	0.0036	0.0027	23.50	0.600
Veh_D	US06	C	1.50	-1.9513	0.0060	2.2899	0.0341	366.5	0.0033	0.0034	0.0031	23.37	1.030
Veh_D	US06	C	1.50	-2.2782	0.0066	2.5177	0.0313	367.7	0.0037	0.0038	0.0033	23.28	0.590
Veh_D	US06	D	1.41	-1.8544	0.0049	1.0140	0.0335	360.9	0.0029	0.0030	0.0022	23.70	0.680
Veh_D	US06	D	1.41	-3.8956	0.0037	0.4646	0.0342	359.0	0.0022	0.0022	0.0017	23.88	0.660
Veh_D	US06	D	1.41	-5.7204	0.0033	0.4077	0.0292	349.5	0.0020	0.0020	0.0015	24.53	0.400
Veh_D	US06	D	1.41	-3.9463	0.0037	0.5240	0.0324	354.5	0.0022	0.0023	0.0017	24.18	0.450
Veh_D	US06	D	1.41	-5.4905	0.0032	0.3494	0.0294	348.8	0.0019	0.0020	0.0015	24.59	0.380
Veh_D	US06	D	1.41	-2.5480	0.0039	0.4725	0.0313	353.1	0.0025	0.0026	0.0016	24.28	0.360
Veh_E	FTP	A	2.72	1.5206	0.0184	0.2208	0.0138	304.9	0.0134	0.0147	0.0052	28.56	4.035
Veh_E	FTP	A	2.72	1.0320	0.0174	0.2422	0.0154	307.0	0.0123	0.0135	0.0053	28.37	4.043
Veh_E	FTP	A	2.72	1.5588	0.0196	0.2260	0.0137	307.7	0.0147	0.0161	0.0053	28.28	4.237
Veh_E	FTP	A	2.72	1.4708	0.0196	0.2518	0.0145	307.8	0.0144	0.0158	0.0054	28.28	4.100
Veh_E	FTP	A	2.72	1.3675	0.0205	0.2548	0.0144	306.2	0.0155	0.0169	0.0053	28.46	0.000
Veh_E	FTP	A	2.72	0.5605	0.0198	0.3093	0.0155	303.4	0.0146	0.0159	0.0054	28.74	4.173
Veh_E	FTP	A	2.72	0.7643	0.0172	0.2047	0.0149	304.0	0.0127	0.0139	0.0047	28.66	4.498
Veh_E	FTP	A	2.72	-0.0245	0.0219	0.1939	0.0106	305.7	0.0173	0.0189	0.0048	28.47	4.065
Veh_E	FTP	A	2.72	2.2474	0.0191	0.1698	0.0124	305.0	0.0147	0.0161	0.0046	28.57	3.683
Veh_E	FTP	A	2.72	1.5258	0.0169	0.1647	0.0128	305.2	0.0126	0.0138	0.0045	28.57	4.060
Veh_E	FTP	A	2.72	1.5251	0.0182	0.1924	0.0132	307.0	0.0135	0.0147	0.0050	28.38	4.473

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_E	FTP	A	2.72	0.7817	0.0183	0.1710	0.0139	303.2	0.0136	0.0149	0.0049	28.76	3.645
Veh_E	FTP	B	1.53	1.8409	0.0173	0.2703	0.0135	305.7	0.0124	0.0136	0.0052	28.46	3.228
Veh_E	FTP	B	1.53	2.3344	0.0159	0.2281	0.0163	307.2	0.0113	0.0124	0.0048	28.37	3.069
Veh_E	FTP	B	1.53	0.3928	0.0167	0.2501	0.0150	307.0	0.0121	0.0132	0.0049	28.37	3.248
Veh_E	FTP	B	1.53	1.6721	0.0171	0.2079	0.0151	308.7	0.0128	0.0141	0.0045	28.19	3.084
Veh_E	FTP	B	1.53	1.6584	0.0179	0.2502	0.0138	310.3	0.0133	0.0145	0.0049	28.10	3.457
Veh_E	FTP	B	1.53	0.4384	0.0162	0.2646	0.0135	307.6	0.0115	0.0125	0.0050	28.28	3.380
Veh_E	FTP	C	1.50	0.9735	0.0159	0.2615	0.0137	304.1	0.0114	0.0124	0.0048	28.41	2.436
Veh_E	FTP	C	1.50	0.9784	0.0177	0.2316	0.0149	304.7	0.0130	0.0142	0.0049	28.32	2.455
Veh_E	FTP	C	1.50	2.2849	0.0200	0.2791	0.0151	306.6	0.0148	0.0162	0.0054	28.13	2.925
Veh_E	FTP	C	1.50	3.4843	0.0184	0.2271	0.0136	306.3	0.0137	0.0150	0.0049	28.23	2.520
Veh_E	FTP	C	1.50	1.0772	0.0188	0.2269	0.0153	305.1	0.0142	0.0155	0.0048	28.32	2.504
Veh_E	FTP	C	1.50	1.5210	0.0145	0.2252	0.0145	305.8	0.0099	0.0108	0.0048	28.23	2.514
Veh_E	FTP	D	1.41	1.9389	0.0158	0.1881	0.0145	304.8	0.0115	0.0131	0.0045	28.18	2.373
Veh_E	FTP	D	1.41	1.5326	0.0144	0.1865	0.0167	304.0	0.0100	0.0113	0.0046	28.27	2.737
Veh_E	FTP	D	1.41	0.8609	0.0147	0.1770	0.0132	303.3	0.0105	0.0119	0.0044	28.37	2.609
Veh_E	FTP	D	1.41	1.0184	0.0149	0.1915	0.0146	303.2	0.0104	0.0118	0.0048	28.36	2.914
Veh_E	FTP	D	1.41	0.8633	0.0163	0.1693	0.0126	305.3	0.0120	0.0136	0.0045	28.18	2.909
Veh_E	FTP	D	1.41	0.8156	0.0149	0.2221	0.0145	304.1	0.0103	0.0117	0.0048	28.27	2.964
Veh_E	US06	A	2.72	-0.4200	0.0149	2.6555	0.0132	347.9	0.0063	0.0065	0.0090	24.77	1.115
Veh_E	US06	A	2.72	-2.1560	0.0144	1.8607	0.0146	343.3	0.0064	0.0066	0.0083	25.21	2.357
Veh_E	US06	A	2.72	-1.3170	0.0156	1.9370	0.0151	343.4	0.0070	0.0072	0.0089	25.20	1.113
Veh_E	US06	A	2.72	-2.0470	0.0160	2.1129	0.0188	347.2	0.0071	0.0073	0.0093	24.90	1.480
Veh_E	US06	A	2.72	-1.7300	0.0174	2.1921	0.0199	338.1	0.0081	0.0083	0.0097	25.54	1.308
Veh_E	US06	A	2.72	-1.9740	0.0148	1.8620	0.0203	337.6	0.0064	0.0066	0.0087	25.58	0.960
Veh_E	US06	A	2.72	-0.2550	0.0165	2.1570	0.0224	343.6	0.0077	0.0080	0.0092	25.11	1.056
Veh_E	US06	A	2.72	-2.3000	0.0145	1.8799	0.0158	343.3	0.0067	0.0069	0.0082	25.21	0.929
Veh_E	US06	A	2.72	-3.1800	0.0156	2.1784	0.0174	337.8	0.0073	0.0075	0.0087	25.54	1.236
Veh_E	US06	A	2.72	-2.6640	0.0172	2.2945	0.0220	343.2	0.0082	0.0085	0.0094	25.16	1.418
Veh_E	US06	A	2.72	-2.5840	0.0175	2.2521	0.0257	344.9	0.0084	0.0086	0.0095	25.02	1.336
Veh_E	US06	A	2.72	-1.4000	0.0157	1.8586	0.0217	338.9	0.0071	0.0073	0.0090	25.51	1.119
Veh_E	US06	B	1.53	-2.3800	0.0161	2.1766	0.0190	343.5	0.0072	0.0074	0.0093	25.17	0.962
Veh_E	US06	B	1.53	-0.9080	0.0159	2.2745	0.0177	343.4	0.0074	0.0076	0.0089	25.16	1.311

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_E	US06	B	1.53	-2.3380	0.0157	2.0830	0.0204	342.2	0.0074	0.0076	0.0087	25.26	1.163
Veh_E	US06	B	1.53	-1.7040	0.0145	2.4309	0.0172	348.3	0.0062	0.0064	0.0087	24.79	1.231
Veh_E	US06	B	1.53	-1.2810	0.0155	2.5716	0.0208	350.4	0.0070	0.0072	0.0089	24.63	1.426
Veh_E	US06	B	1.53	-1.5280	0.0143	1.9097	0.0194	344.6	0.0066	0.0068	0.0081	25.06	0.855
Veh_E	US06	C	1.50	-2.1060	0.0166	2.4967	0.0169	342.8	0.0075	0.0077	0.0095	24.93	0.890
Veh_E	US06	C	1.50	-1.7730	0.0189	3.0796	0.0198	345.4	0.0089	0.0091	0.0104	24.72	1.770
Veh_E	US06	C	1.50	-2.6530	0.0169	2.3460	0.0214	341.3	0.0076	0.0078	0.0097	25.09	0.949
Veh_E	US06	C	1.50	-0.8850	0.0179	3.1456	0.0192	352.7	0.0086	0.0088	0.0097	24.16	1.644
Veh_E	US06	C	1.50	-0.1680	0.0138	2.2622	0.0189	348.3	0.0063	0.0065	0.0078	24.60	0.727
Veh_E	US06	C	1.50	-1.9850	0.0153	2.2006	0.0166	348.2	0.0069	0.0071	0.0088	24.61	1.230
Veh_E	US06	D	1.41	-0.8640	0.0155	2.1338	0.0197	339.6	0.0070	0.0072	0.0089	25.06	0.946
Veh_E	US06	D	1.41	-0.8640	0.0155	2.1338	0.0197	339.6	0.0070	0.0072	0.0089	25.06	1.494
Veh_E	US06	D	1.41	-1.0580	0.0144	1.8457	0.0197	341.6	0.0066	0.0068	0.0082	24.95	0.931
Veh_E	US06	D	1.41	-2.5510	0.0130	1.9595	0.0177	340.4	0.0055	0.0057	0.0079	25.08	1.016
Veh_E	US06	D	1.41	-2.1640	0.0138	1.5418	0.0163	333.0	0.0062	0.0064	0.0079	25.65	0.976
Veh_E	US06	D	1.41	-4.0690	0.0158	2.0421	0.0206	335.2	0.0068	0.0070	0.0094	25.44	1.139
Veh_F	FTP	A	2.72	4.3485	0.0269	0.0665	0.0046	243.4	0.0227	0.0249	0.0040	35.82	0.796
Veh_F	FTP	A	2.72	4.1936	0.0372	0.0970	0.0078	241.8	0.0330	0.0362	0.0041	36.03	0.830
Veh_F	FTP	A	2.72	3.6327	0.0307	0.0832	0.0058	240.7	0.0267	0.0293	0.0038	36.20	0.791
Veh_F	FTP	A	2.72	3.7492	0.0288	0.0729	0.0048	240.6	0.0242	0.0265	0.0044	36.23	0.874
Veh_F	FTP	A	2.72	3.7733	0.0261	0.0642	0.0047	240.8	0.0218	0.0239	0.0042	36.20	0.774
Veh_F	FTP	A	2.72	3.7804	0.0271	0.0672	0.0045	240.4	0.0227	0.0248	0.0044	36.26	0.778
Veh_F	FTP	A	2.72	3.9452	0.0273	0.0629	0.0061	240.2	0.0232	0.0254	0.0040	36.28	0.730
Veh_F	FTP	A	2.72	3.7737	0.0292	0.0644	0.0054	240.7	0.0250	0.0274	0.0041	36.22	0.736
Veh_F	FTP	B	1.53	3.8287	0.0301	0.0847	0.0053	241.6	0.0261	0.0286	0.0040	36.07	0.537
Veh_F	FTP	B	1.53	3.9421	0.0274	0.0753	0.0054	240.7	0.0234	0.0257	0.0039	36.21	0.442
Veh_F	FTP	B	1.53	3.6580	0.0250	0.0704	0.0052	239.3	0.0218	0.0239	0.0032	36.42	0.421
Veh_F	FTP	B	1.53	3.5104	0.0274	0.0712	0.0057	241.4	0.0236	0.0259	0.0037	36.10	0.479
Veh_F	FTP	Base	1.49	4.0119	0.0265	0.0809	0.0050	238.8	0.0223	0.0245	0.0041	36.22	0.398
Veh_F	FTP	Base	1.49	4.4680	0.0266	0.0846	0.0054	238.5	0.0226	0.0248	0.0039	36.27	0.430
Veh_F	FTP	Base	1.49	4.1589	0.0293	0.0839	0.0058	237.5	0.0257	0.0282	0.0035	36.42	0.399
Veh_F	FTP	Base	1.49	4.5260	0.0281	0.0846	0.0053	236.8	0.0238	0.0261	0.0042	36.53	0.527
Veh_F	FTP	C	1.50	4.0776	0.0257	0.0758	0.0058	236.5	0.0218	0.0239	0.0038	36.55	0.362

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_F	FTP	C	1.50	3.9239	0.0275	0.0891	0.0051	237.6	0.0229	0.0251	0.0045	36.37	0.436
Veh_F	FTP	C	1.50	4.0739	0.0265	0.0810	0.0051	237.2	0.0222	0.0243	0.0042	36.43	0.396
Veh_F	FTP	C	1.50	4.4208	0.0254	0.0703	0.0048	238.0	0.0211	0.0231	0.0042	36.32	0.453
Veh_F	FTP	D	1.41	3.5123	0.0254	0.0739	0.0052	236.8	0.0210	0.0239	0.0042	36.28	0.363
Veh_F	FTP	D	1.41	3.8794	0.0250	0.0766	0.0055	237.2	0.0206	0.0234	0.0043	36.23	0.282
Veh_F	FTP	D	1.41	4.2262	0.0253	0.0795	0.0056	238.3	0.0210	0.0239	0.0042	36.05	0.397
Veh_F	FTP	D	1.41	4.0540	0.0257	0.0774	0.0054	238.6	0.0213	0.0241	0.0043	36.01	0.407
Veh_F	US06	A	2.72	-2.1154	0.0210	1.3062	0.0232	268.8	0.0167	0.0172	0.0042	32.20	1.175
Veh_F	US06	A	2.72	-2.8137	0.0208	1.6310	0.0070	271.1	0.0177	0.0182	0.0030	31.87	0.785
Veh_F	US06	A	2.72	-3.3760	0.0167	1.3348	0.0252	265.7	0.0141	0.0146	0.0025	32.57	1.052
Veh_F	US06	A	2.72	-2.9746	0.0173	1.1416	0.0054	262.3	0.0135	0.0139	0.0037	33.02	0.526
Veh_F	US06	A	2.72	-3.1937	0.0143	0.8279	0.0059	261.6	0.0111	0.0114	0.0031	33.18	0.593
Veh_F	US06	A	2.72	-3.7014	0.0162	1.3085	0.0143	262.3	0.0125	0.0129	0.0037	32.99	0.964
Veh_F	US06	A	2.72	-3.3724	0.0174	1.0332	0.0064	263.4	0.0140	0.0144	0.0034	32.90	0.646
Veh_F	US06	A	2.72	-3.0788	0.0177	1.0800	0.0072	263.1	0.0140	0.0144	0.0036	32.94	0.553
Veh_F	US06	A	2.72	-2.7978	0.0169	1.2656	0.0065	263.2	0.0132	0.0136	0.0037	32.89	0.764
Veh_F	US06	B	1.53	-3.1159	0.0186	1.3568	0.0062	265.3	0.0151	0.0156	0.0034	32.61	0.558
Veh_F	US06	B	1.53	-2.5712	0.0179	1.3157	0.0066	264.8	0.0145	0.0149	0.0034	32.68	0.719
Veh_F	US06	B	1.53	-2.9081	0.0165	1.3549	0.0058	264.0	0.0136	0.0140	0.0028	32.77	0.788
Veh_F	US06	B	1.53	-3.4271	0.0169	1.3159	0.0216	263.5	0.0135	0.0139	0.0033	32.84	0.674
Veh_F	US06	Base	1.49	-2.5266	0.0166	1.3110	0.0207	262.7	0.0130	0.0133	0.0035	32.71	0.594
Veh_F	US06	Base	1.49	-2.4936	0.0162	1.3302	0.0200	260.5	0.0123	0.0126	0.0038	32.97	0.436
Veh_F	US06	Base	1.49	-2.7684	0.0182	1.3306	0.0067	260.4	0.0140	0.0144	0.0041	32.99	0.498
Veh_F	US06	Base	1.49	-3.0603	0.0149	1.0054	0.0056	260.1	0.0117	0.0120	0.0032	33.08	0.733
Veh_F	US06	C	1.50	Status	0.0180	1.3457	0.0058	262.5	0.0139	0.0144	0.0040	32.68	0.741
Veh_F	US06	C	1.50	-3.3117	0.0147	0.7226	0.0134	259.7	0.0115	0.0119	0.0031	33.16	0.651
Veh_F	US06	C	1.50	-2.7071	0.0157	0.6826	0.0060	261.2	0.0127	0.0131	0.0029	32.98	0.279
Veh_F	US06	C	1.50	-3.4144	0.0143	0.7350	0.0059	260.3	0.0111	0.0115	0.0031	33.08	0.435
Veh_F	US06	D	1.41	-3.6917	0.0169	0.9392	0.0067	258.3	0.0134	0.0138	0.0034	33.09	0.441
Veh_F	US06	D	1.41	-3.0828	0.0179	1.1532	0.0242	259.1	0.0136	0.0140	0.0042	32.94	0.371
Veh_F	US06	D	1.41	-3.8413	0.0178	0.9391	0.0062	258.4	0.0145	0.0150	0.0032	33.08	0.441
Veh_F	US06	D	1.41	-3.5863	0.0158	0.7907	0.0141	258.4	0.0125	0.0129	0.0032	33.11	0.595
Veh_G	FTP	A	2.72	-0.0711	0.0185	0.1092	0.0157	387.7	0.0137	0.0150	0.0051	22.48	1.639

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_G	FTP	A	2.72	-0.0773	0.0164	0.1009	0.0145	390.0	0.0130	0.0143	0.0044	22.35	1.634
Veh_G	FTP	A	2.72	-0.1661	0.0156	0.1202	0.0124	387.7	0.0110	0.0120	0.0051	22.48	1.665
Veh_G	FTP	A	2.72	-0.1129	0.0132	0.1165	0.0119	390.2	0.0089	0.0098	0.0048	22.33	1.511
Veh_G	FTP	A	2.72	0.0180	0.0166	0.1051	0.0147	389.7	0.0114	0.0125	0.0056	22.36	2.318
Veh_G	FTP	A	2.72	-0.0885	0.0147	0.1083	0.0149	390.2	0.0098	0.0107	0.0053	22.33	2.036
Veh_G	FTP	A	2.72	-0.2056	0.0147	0.0993	0.0112	387.8	0.0101	0.0111	0.0049	22.57	1.964
Veh_G	FTP	A	2.72	-0.2139	0.0140	0.0994	0.0096	390.8	0.0094	0.0103	0.0050	22.39	2.416
Veh_G	FTP	A	2.72	-0.2697	0.0125	0.0907	0.0132	389.2	0.0087	0.0096	0.0042	22.48	2.738
Veh_G	FTP	A	2.72	-0.1074	0.0155	0.1048	0.0122	387.5	0.0103	0.0113	0.0056	22.58	1.829
Veh_G	FTP	A	2.72	-0.0160	0.0162	0.1093	0.0106	386.2	0.0114	0.0125	0.0054	22.66	1.903
Veh_G	FTP	B	1.53	-0.1953	0.0130	0.1170	0.0151	385.7	0.0095	0.0104	0.0049	22.71	0.749
Veh_G	FTP	B	1.53	-0.2148	0.0143	0.1135	0.0136	383.5	0.0100	0.0110	0.0049	22.84	0.931
Veh_G	FTP	B	1.53	-0.2100	0.0145	0.1102	0.0148	385.4	0.0111	0.0122	0.0049	22.73	0.884
Veh_G	FTP	B	1.53	-0.1874	0.0127	0.1168	0.0120	387.9	0.0090	0.0098	0.0047	22.59	0.724
Veh_G	FTP	Base	1.49	-0.1389	0.0157	0.1004	0.0149	381.9	0.0115	0.0126	0.0045	22.80	0.810
Veh_G	FTP	Base	1.49	-0.2799	0.0144	0.1170	0.0134	384.6	0.0098	0.0108	0.0050	22.64	0.885
Veh_G	FTP	Base	1.49	-0.2799	0.0156	0.1044	0.0131	386.6	0.0109	0.0119	0.0051	22.52	1.095
Veh_G	FTP	C	1.50	-0.2222	0.0139	0.1165	0.0148	383.0	0.0097	0.0106	0.0050	22.87	0.628
Veh_G	FTP	C	1.50	-0.2997	0.0153	0.1039	0.0108	386.3	0.0111	0.0122	0.0048	22.50	0.635
Veh_G	FTP	C	1.50	-0.1549	0.0129	0.1192	0.0147	385.5	0.0083	0.0091	0.0049	22.55	0.750
Veh_G	FTP	C	1.50	-0.1349	0.0158	0.0997	0.0126	382.8	0.0117	0.0128	0.0043	22.70	0.671
Veh_G	FTP	C	1.50	-0.1806	0.0143	0.1087	0.0136	383.3	0.0103	0.0113	0.0049	22.67	0.754
Veh_G	FTP	D	1.41	-0.2246	0.0138	0.0960	0.0153	382.7	0.0102	0.0116	0.0043	22.65	0.550
Veh_G	FTP	D	1.41	-0.1444	0.0144	0.1009	0.0160	379.5	0.0097	0.0110	0.0052	22.84	0.556
Veh_G	FTP	D	1.41	-0.3152	0.0144	0.1043	0.0145	385.9	0.0098	0.0111	0.0050	22.47	0.530
Veh_G	FTP	D	1.41	-0.4318	0.0139	0.0909	0.0132	382.2	0.0098	0.0111	0.0043	22.69	0.647
Veh_G	FTP	D	1.41	-0.4268	0.0144	0.1008	0.0133	382.0	0.0107	0.0122	0.0048	22.69	0.716
Veh_G	FTP	D	1.41	-0.1957	0.0120	0.1090	0.0131	385.2	0.0078	0.0088	0.0050	22.51	0.829
Veh_G	US06	A	2.72	-4.8984	0.0207	3.7817	0.0162	355.0	0.0120	0.0124	0.0092	24.15	0.515
Veh_G	US06	A	2.72	-4.9236	0.0158	4.1389	0.0161	359.9	0.0070	0.0072	0.0093	23.79	0.684
Veh_G	US06	A	2.72	-4.8919	0.0243	5.1518	0.0141	360.0	0.0143	0.0148	0.0105	23.68	1.156
Veh_G	US06	A	2.72	-4.7989	0.0224	5.1221	0.0162	360.3	0.0128	0.0132	0.0102	23.67	1.328
Veh_G	US06	A	2.72	-5.1071	0.0189	2.4139	0.0129	367.3	0.0113	0.0116	0.0081	23.49	1.969

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_G	US06	A	2.72	-4.9432	0.0168	1.0254	0.0149	368.1	0.0103	0.0106	0.0068	23.58	1.329
Veh_G	US06	A	2.72	-4.8650	0.0140	1.2709	0.0172	358.1	0.0080	0.0083	0.0064	24.31	1.150
Veh_G	US06	A	2.72	-5.0837	0.0171	2.4253	0.0188	359.6	0.0098	0.0101	0.0077	24.09	1.699
Veh_G	US06	A	2.72	-4.7809	0.0198	3.7526	0.0167	358.7	0.0115	0.0118	0.0088	24.01	1.564
Veh_G	US06	A	2.72	-4.5705	0.0216	4.1953	0.0192	362.1	0.0124	0.0127	0.0098	23.75	0.975
Veh_G	US06	A	2.72	-5.0805	0.0189	2.9250	0.0211	359.8	0.0109	0.0113	0.0084	24.03	1.689
Veh_G	US06	B	1.53	-4.9471	0.0211	3.4555	0.0162	362.7	0.0127	0.0131	0.0089	23.69	1.702
Veh_G	US06	B	1.53	-4.9882	0.0213	4.0895	0.0154	365.0	0.0125	0.0129	0.0093	23.48	0.824
Veh_G	US06	B	1.53	-4.9539	0.0175	3.5708	0.0149	357.1	0.0097	0.0100	0.0083	24.16	1.047
Veh_G	US06	B	1.53	-5.1285	0.0169	2.4787	0.0157	356.9	0.0098	0.0101	0.0074	24.29	1.233
Veh_G	US06	B	1.53	-4.9359	0.0164	2.8579	0.0168	357.3	0.0091	0.0093	0.0077	24.22	1.140
Veh_G	US06	Base	1.49	-4.9778	0.0179	3.5458	0.0137	354.9	0.0098	0.0101	0.0085	24.16	1.225
Veh_G	US06	Base	1.49	-4.8662	0.0191	2.9878	0.0160	357.8	0.0111	0.0114	0.0085	24.03	0.729
Veh_G	US06	Base	1.49	-4.6541	0.0181	3.1864	0.0180	356.1	0.0101	0.0104	0.0085	24.12	1.461
Veh_G	US06	Base	1.49	-4.9486	0.0148	1.6395	0.0158	356.7	0.0082	0.0085	0.0069	24.25	0.765
Veh_G	US06	C	1.50	-5.0638	0.0224	4.7061	0.0160	355.1	0.0131	0.0135	0.0098	23.98	1.228
Veh_G	US06	C	1.50	-4.9671	0.0042	4.0943	0.0166	356.1	0.0000	0.0000	0.0093	23.98	0.931
Veh_G	US06	C	1.50	-5.0850	0.0204	4.2254	0.0140	355.5	0.0116	0.0119	0.0093	24.01	0.805
Veh_G	US06	C	1.50	-5.0089	0.0210	4.6245	0.0141	355.3	0.0117	0.0121	0.0098	23.98	1.468
Veh_G	US06	C	1.50	-4.9607	0.0176	3.3848	0.0151	355.7	0.0094	0.0097	0.0086	24.08	2.485
Veh_G	US06	D	1.41	-5.0395	0.0123	0.5310	0.0133	352.1	0.0070	0.0072	0.0056	24.58	1.215
Veh_G	US06	D	1.41	-4.8136	0.0146	1.2355	0.0163	352.0	0.0085	0.0088	0.0064	24.51	2.013
Veh_G	US06	D	1.41	-4.2929	0.0117	0.5682	0.0149	354.8	0.0067	0.0069	0.0053	24.38	1.102
Veh_G	US06	D	1.41	-5.0716	0.0118	0.5775	0.0127	354.7	0.0066	0.0068	0.0055	24.39	1.511
Veh_G	US06	D	1.41	-5.0776	0.0109	0.3779	0.0131	353.0	0.0061	0.0063	0.0051	24.53	1.699
Veh_G	US06	D	1.41	-4.9898	0.0133	0.3986	0.0173	352.2	0.0078	0.0080	0.0058	24.58	2.027
Veh_H	FTP	A	2.72	1.1966	0.0108	0.1991	0.0086	283.7	0.0068	0.0074	0.0046	31.08	2.117
Veh_H	FTP	A	2.72	-3.0904	0.0124	0.2154	0.0061	281.6	0.0065	0.0072	0.0063	31.31	1.989
Veh_H	FTP	A	2.72	1.1246	0.0099	0.1987	0.0090	288.7	0.0055	0.0060	0.0049	30.54	2.169
Veh_H	FTP	A	2.72	-0.7497	0.0156	0.2104	0.0045	280.2	0.0119	0.0130	0.0040	31.46	2.868
Veh_H	FTP	A	2.72	-2.9534	0.0144	0.2273	0.0064	273.2	0.0104	0.0114	0.0043	32.27	1.799
Veh_H	FTP	A	2.72	1.0880	0.0106	0.1849	0.0046	283.1	0.0069	0.0076	0.0040	31.14	1.764
Veh_H	FTP	A	2.72	0.9571	0.0100	0.1542	0.0071	276.5	0.0054	0.0059	0.0049	31.89	2.227

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_H	FTP	A	2.72	1.2741	0.0130	0.2480	0.0070	274.5	0.0080	0.0088	0.0050	32.11	2.777
Veh_H	FTP	A	2.72	0.8508	0.0130	0.2140	0.0060	275.5	0.0090	0.0099	0.0040	32.00	2.441
Veh_H	FTP	B	1.53	-1.9547	0.0160	0.2590	0.0080	279.5	0.0110	0.0121	0.0050	31.57	1.704
Veh_H	FTP	B	1.53	-3.0383	0.0110	0.1656	0.0036	277.5	0.0079	0.0087	0.0036		1.855
Veh_H	FTP	B	1.53	-1.5879	0.0138	0.1951	0.0034	278.2	0.0107	0.0117	0.0032	31.73	1.762
Veh_H	FTP	B	1.53	-2.1753	0.0132	0.2029	0.0055	281.8	0.0083	0.0091	0.0054	31.32	1.580
Veh_H	FTP	B	1.53	-2.8807	0.0120	0.2561	0.0041	271.5	0.0079	0.0087	0.0043	32.50	1.962
Veh_H	FTP	Base	1.49	-1.5584	0.0173	0.3143	0.0057	300.2	0.0125	0.0137	0.0052	29.19	1.900
Veh_H	FTP	Base	1.49	-3.6243	0.1132	0.2267	0.0049	296.4	0.0070	0.0077	0.0047	29.58	1.311
Veh_H	FTP	Base	1.49	-2.0667	0.0127	0.2659	0.0045	286.7	0.0091	0.0100	0.0041	30.57	1.643
Veh_H	FTP	Base	1.49	-2.5854	0.0130	0.2670	0.0050	273.3	0.0070	0.0077	0.0060	32.06	1.446
Veh_H	FTP	Base	1.49	1.2141	0.0120	0.2660	0.0080	281.6	0.0080	0.0088	0.0050	31.12	1.346
Veh_H	FTP	Base	1.49	-2.4904	0.0135	0.2568	0.0043	301.2	0.0082	0.0090	0.0059	29.10	1.666
Veh_H	FTP	Base	1.49	0.3637	0.0122	0.2484	0.0062	278.0	0.0079	0.0087	0.0046	31.53	1.736
Veh_H	FTP	Base	1.49	-2.2141	0.0120	0.1910	0.0070	263.3	0.0080	0.0088	0.0050	33.31	2.245
Veh_H	FTP	Base	1.49	-0.1410	0.0120	0.2050	0.0160	275.8	0.0070	0.0077	0.0060	31.79	1.297
Veh_H	FTP	Base	1.49	-1.7558	0.0131	0.4092	0.0047	307.6	0.0093	0.0103	0.0042	28.48	2.316
Veh_H	FTP	C	1.50	-2.9281	0.0154	0.2838	0.0043	278.5	0.0109	0.0119	0.0047	31.45	2.379
Veh_H	FTP	C	1.50	-2.5473	0.0132	0.2299	0.0048	275.9	0.0075	0.0082	0.0060	31.75	1.513
Veh_H	FTP	C	1.50	1.0443	0.0120	0.2010	0.0070	284.5	0.0080	0.0088	0.0040	30.80	1.145
Veh_H	FTP	C	1.50	-2.4439	0.0170	0.2380	0.0060	271.6	0.0120	0.0132	0.0050	32.25	1.339
Veh_H	FTP	D	1.41	-2.8565	0.0130	0.2070	0.0040	268.5	0.0070	0.0079	0.0060	32.56	1.180
Veh_H	FTP	D	1.41	2.0585	0.0170	0.3490	0.0090	280.5	0.0110	0.0125	0.0070	31.14	1.581
Veh_H	FTP	D	1.41	-1.2940	0.0160	0.2150	0.0070	272.6	0.0110	0.0125	0.0050	32.07	1.222
Veh_H	FTP	D	1.41	1.1680	0.0160	0.1950	0.0040	270.0	0.0120	0.0136	0.0050	32.38	1.549
Veh_H	US06	A	2.72	-3.8910	0.0015	3.9894	0.0087	342.8	0.0000	0.0000	0.0026	25.29	1.539
Veh_H	US06	A	2.72	-9.4400	0.0009	0.7826	0.0062	334.4	0.0003	0.0004	0.0008	26.31	0.723
Veh_H	US06	A	2.72	-5.8940	0.0015	3.1535	0.0051	338.2	0.0000	0.0000	0.0024	25.72	1.669
Veh_H	US06	A	2.72	-4.6890	0.0019	3.1946	0.0025	343.4	0.0000	0.0000	0.0025	25.34	1.443
Veh_H	US06	A	2.72	-11.0790	0.0009	0.6820	0.0151	322.3	0.0000	0.0000	0.0011	27.30	1.022
Veh_H	US06	A	2.72	-9.8610	0.0005	0.8343	0.0162	327.0	0.0000	0.0000	0.0011	26.89	0.943
Veh_H	US06	A	2.72	-9.3320	0.0010	0.3010	0.0040	333.3	0.0000	0.0000	0.0010	26.45	1.021
Veh_H	US06	A	2.72	-5.4730	0.0030	5.5780	0.0090	335.4	0.0000	0.0000	0.0030	25.65	1.587

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_H	US06	A	2.72	-3.5720	0.0010	2.1840	0.0040	333.0	0.0000	0.0000	0.0010	26.24	1.216
Veh_H	US06	B	1.53	-11.5600	0.0008	0.8770	0.0041	319.7	0.0000	0.0000	0.0013	27.52	0.831
Veh_H	US06	B	1.53	-9.8130	0.0005	0.0623	0.0052	331.4	0.0000	0.0000	0.0009	26.66	1.093
Veh_H	US06	B	1.53	-6.9750	0.0009	0.0981	0.0040	333.5	0.0002	0.0002	0.0009	26.49	1.089
Veh_H	US06	B	1.53	-9.0430	0.0008	0.6267	0.0069	335.4	0.0001	0.0001	0.0010	26.27	0.805
Veh_H	US06	B	1.53	-3.3370	0.0010	1.8690	0.0040	343.8	0.0010	0.0010	0.0000	25.49	1.554
Veh_H	US06	Base	1.49	-4.8870	0.0009	1.2663	0.0052	342.9	0.0001	0.0001	0.0009	25.45	1.251
Veh_H	US06	Base	1.49	-8.6260	0.0022	2.0180	0.0024	340.6	0.0001	0.0001	0.0022	25.54	0.663
Veh_H	US06	Base	1.49	-2.7810	0.0016	3.4919	0.0069	339.6	0.0000	0.0000	0.0022	25.44	1.188
Veh_H	US06	Base	1.49	-7.0030	0.0012	0.9281	0.0085	327.3	0.0001	0.0001	0.0011	26.70	1.019
Veh_H	US06	Base	1.49	-9.9290	0.0009	0.6942	0.0092	333.3	0.0001	0.0001	0.0009	26.25	0.724
Veh_H	US06	Base	1.49	-7.9650	0.0009	0.8058	0.0083	340.7	0.0001	0.0001	0.0008	25.67	0.773
Veh_H	US06	Base	1.49	-9.3990	0.0010	1.0830	0.0040	326.0	0.0000	0.0000	0.0020	26.79	0.914
Veh_H	US06	Base	1.49	-4.7630	0.0020	4.1730	0.0030	331.3	0.0000	0.0000	0.0030	25.98	1.209
Veh_H	US06	Base	1.49	-1.9710	0.0020	3.6660	0.0040	346.5	0.0000	0.0000	0.0020	24.93	1.366
Veh_H	US06	Base	1.49	-5.6700	0.0010	4.8720	0.0040	332.1	0.0000	0.0000	0.0020	25.84	1.076
Veh_H	US06	C	1.50	-8.0960	0.0020	2.9100	0.0040	326.5	0.0000	0.0000	0.0030	26.50	7.262
Veh_H	US06	C	1.50	-8.4660	0.0020	2.0900	0.0050	332.8	0.0000	0.0000	0.0020	26.10	1.078
Veh_H	US06	C	1.50	-4.5880	0.0030	4.2890	0.0040	343.6	0.0000	0.0000	0.0030	25.04	1.682
Veh_H	US06	C	1.50	-10.3600	0.0010	1.6300	0.0030	322.3	0.0000	0.0000	0.0020	27.00	0.643
Veh_H	US06	C	1.50	-2.7020	0.0020	4.2650	0.0050	338.9	0.0000	0.0000	0.0030	25.39	1.141
Veh_H	US06	D	1.41	-10.7400	0.0008	0.4487	0.0120	323.6	0.0000	0.0000	0.0010	26.99	0.844
Veh_H	US06	D	1.41	-3.5840	0.0010	1.6510	0.0100	346.7	0.0000	0.0000	0.0020	25.06	1.334
Veh_H	US06	D	1.41	-8.7480	0.0020	0.8300	0.0060	320.8	0.0000	0.0000	0.0020	27.17	0.657
Veh_H	US06	D	1.41	-5.6260	0.0010	1.6810	0.0050	325.5	0.0000	0.0000	0.0020	26.68	0.441
Veh_I	FTP	A	2.72	-0.3238	0.0423	0.1478	0.0268	222.1	0.0383	0.0420	0.0090	39.20	4.106
Veh_I	FTP	A	2.72	-0.2971	0.0558	0.1684	0.0316	222.8	0.0465	0.0509	0.0091	39.08	4.100
Veh_I	FTP	A	2.72	-0.4281	0.0565	0.1455	0.0323	218.1	0.0472	0.0518	0.0090	39.93	4.040
Veh_I	FTP	A	2.72	-0.3193	0.0552	0.1457	0.0298	222.2	0.0457	0.0501	0.0092	39.18	4.467
Veh_I	FTP	A	2.72	-0.7699	0.0549	0.1359	0.0320	214.6	0.0442	0.0484	0.0104	40.57	3.598
Veh_I	FTP	A	2.72	-0.6044	0.0460	0.1637	0.0306	213.7	0.0362	0.0397	0.0095	40.74	3.487
Veh_I	FTP	A	2.72	-0.4664	0.0537	0.1577	0.0302	209.8	0.0427	0.0468	0.0107	41.49	3.233
Veh_I	FTP	B	1.53	-0.6194	0.0520	0.1512	0.0293	216.4	0.0433	0.0474	0.0085	40.22	2.137

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_I	FTP	B	1.53	-0.5352	0.0617	0.1687	0.0372	215.2	0.0519	0.0569	0.0096	40.45	2.142
Veh_I	FTP	B	1.53	-0.7236	0.0487	0.1314	0.0273	217.4	0.0398	0.0436	0.0087	40.05	2.413
Veh_I	FTP	B	1.53	-0.5473	0.0580	0.1733	0.0295	216.1	0.0482	0.0528	0.0096	40.28	1.823
Veh_I	FTP	Base	1.49	-0.6092	0.0497	0.1536	0.0291	216.7	0.0400	0.0439	0.0095	39.89	1.566
Veh_I	FTP	Base	1.49	-0.6131	0.0455	0.1575	0.0293	216.5	0.0355	0.0390	0.0097	39.92	2.102
Veh_I	FTP	Base	1.49	-0.3521	0.0552	0.1655	0.0352	216.3	0.0462	0.0507	0.0088	39.96	1.847
Veh_I	FTP	C	1.50	-0.2608	0.0513	0.1474	0.0304	216.1	0.0435	0.0476	0.0076	39.95	1.697
Veh_I	FTP	C	1.50	-0.5272	0.0544	0.1683	0.0354	217.6	0.0443	0.0486	0.0099	39.68	2.023
Veh_I	FTP	C	1.50	-0.8080	0.0517	0.1528	0.0358	215.6	0.0417	0.0457	0.0098	40.05	1.937
Veh_I	FTP	C	1.50	-0.5645	0.0548	0.1480	0.0340	216.7	0.0444	0.0487	0.0102	39.85	1.782
Veh_I	FTP	D	1.41	-0.4997	0.0471	0.1253	0.0290	214.9	0.0366	0.0415	0.0102	39.95	1.322
Veh_I	FTP	D	1.41	-0.4470	0.0561	0.1434	0.0328	214.1	0.0461	0.0523	0.0098	40.09	1.530
Veh_I	FTP	D	1.41	-0.3437	0.0490	0.1657	0.0336	215.8	0.0388	0.0440	0.0099	39.77	1.512
Veh_I	FTP	D	1.41	-0.3336	0.0604	0.1791	0.0360	216.9	0.0501	0.0568	0.0100	39.56	2.196
Veh_I	US06	A	2.72	-4.1284	0.1064	3.0459	0.0060	246.8	0.0772	0.0795	0.0285	34.63	1.971
Veh_I	US06	A	2.72	-3.8958	0.1124	3.0428	0.0059	246.0	0.0806	0.0830	0.0311	34.73	1.848
Veh_I	US06	A	2.72	-4.0354	0.0973	3.0322	0.0057	247.8	0.0714	0.0735	0.0252	34.50	2.254
Veh_I	US06	A	2.72	-4.1313	0.1293	3.0431	0.0053	245.1	0.0940	0.0968	0.0344	34.85	3.174
Veh_I	US06	A	2.72	-4.4741	0.0712	3.0316	0.0053	240.6	0.0412	0.0425	0.0292	35.52	2.057
Veh_I	US06	A	2.72	-4.7854	0.0833	3.0435	0.0047	230.6	0.0527	0.0542	0.0299	37.02	0.991
Veh_I	US06	A	2.72	-4.7451	0.0717	3.0331	0.0048	238.3	0.0426	0.0439	0.0283	35.85	1.263
Veh_I	US06	B	1.53	-3.4919	0.0897	3.0447	0.0052	239.4	0.0607	0.0625	0.0283	35.68	1.019
Veh_I	US06	B	1.53	-4.6258	0.0554	3.0410	0.0051	240.2	0.0344	0.0354	0.0205	35.58	0.904
Veh_I	US06	B	1.53	-4.0180	0.0823	3.0615	0.0057	235.1	0.0550	0.0566	0.0267	36.31	0.628
Veh_I	US06	B	1.53	-4.7359	0.0615	3.0502	0.0057	240.8	0.0393	0.0404	0.0216	35.48	0.907
Veh_I	US06	Base	1.49	-3.9782	0.0712	3.0541	0.0055	234.2	0.0469	0.0483	0.0237	36.19	0.988
Veh_I	US06	Base	1.49	-4.1763	0.0736	3.0567	0.0049	233.5	0.0475	0.0489	0.0255	36.30	0.876
Veh_I	US06	Base	1.49	-3.9243	0.0753	3.0568	0.0051	242.1	0.0475	0.0489	0.0271	35.03	0.946
Veh_I	US06	C	1.50	-4.0027	0.0700	3.0427	0.0053	235.4	0.0489	0.0504	0.0206	35.99	0.862
Veh_I	US06	C	1.50	-3.5276	0.0832	3.0410	0.0054	238.8	0.0552	0.0569	0.0273	35.48	0.990
Veh_I	US06	C	1.50	-4.0221	0.0790	3.0504	0.0054	240.7	0.0534	0.0550	0.0250	35.20	0.785
Veh_I	US06	C	1.50	-3.6385	0.0737	3.0557	0.0053	232.8	0.0497	0.0512	0.0234	36.37	0.875
Veh_I	US06	C	1.50	-4.2774	0.0765	3.0465	0.0050	234.5	0.0483	0.0498	0.0275	36.12	1.099

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_I	US06	D	1.41	-4.2099	0.0288	3.0445	0.0052	230.1	0.0156	0.0160	0.0129	36.58	0.680
Veh_I	US06	D	1.41	-4.1549	0.0352	3.0453	0.0046	235.5	0.0178	0.0184	0.0170	35.77	0.566
Veh_I	US06	D	1.41	-4.0723	0.0398	3.0619	0.0051	231.0	0.0225	0.0232	0.0169	36.45	1.005
Veh_I	US06	D	1.41	-4.0526	0.0281	3.0593	0.0055	237.7	0.0164	0.0169	0.0114	35.44	0.671
Veh_J	FTP	A	2.72	4.7130	0.0222	0.4530	0.0194	487.7	0.0185	0.0203	0.0036	13.44	1.401
Veh_J	FTP	A	2.72	-0.8618	0.0205	0.4456	0.0148	476.8	0.0168	0.0184	0.0039	13.14	0.901
Veh_J	FTP	A	2.72	-0.7266	0.0242	0.5247	0.0165	477.7	0.0199	0.0218	0.0041	13.17	0.924
Veh_J	FTP	A	2.72	0.1830	0.0250	0.5460	0.0150	479.8	0.0203	0.0223	0.0052	13.23	1.702
Veh_J	FTP	A	2.72	1.5716	0.0210	0.3873	0.0169	478.8	0.0172	0.0188	0.0035	13.20	0.945
Veh_J	FTP	A	2.72	0.8918	0.0252	0.5539	0.0126	484.4	0.0200	0.0219	0.0053	13.36	1.604
Veh_J	FTP	A	2.72	0.4716	0.0206	0.4601	0.0149	480.1	0.0171	0.0188	0.0038	13.23	
Veh_J	FTP	A	2.72	3.7144	0.0235	0.6104	0.0128	487.6	0.0171	0.0188	0.0047	13.45	1.629
Veh_J	FTP	A	2.72	5.5957	0.0152	0.3729	0.0177	487.8	0.0129	0.0141	0.0029	13.44	1.638
Veh_J	FTP	A	2.72	3.8664	0.0219	0.5728	0.0155	489.0	0.0178	0.0195	0.0049	13.48	6.141
Veh_J	FTP	B	1.53	-1.1049	0.0162	0.3242	0.0135	476.5	0.0137	0.0150	0.0026	12.87	1.479
Veh_J	FTP	B	1.53	-1.9137	0.0238	0.5783	0.0102	475.8	0.0192	0.0211	0.0049	13.12	
Veh_J	FTP	B	1.53	0.0278	0.0240	0.5528	0.0136	476.6	0.0197	0.0216	0.0046	13.14	0.893
Veh_J	FTP	B	1.53	-0.9470	0.0240	0.4697	0.0127	475.5	0.0197	0.0216	0.0043	13.11	0.689
Veh_J	FTP	Base	1.49	-0.3797	0.0255	0.5554	0.0105	477.0	0.0214	0.0235	0.0038	12.96	0.813
Veh_J	FTP	Base	1.49	-2.5556	0.0209	0.5041	0.0101	472.2	0.0188	0.0206	0.0046	13.08	1.277
Veh_J	FTP	Base	1.49	-2.6390	0.0333	0.5424	0.0103	475.8	0.0284	0.0312	0.0051	13.18	0.881
Veh_J	FTP	Base	1.49	-1.2825	0.0172	0.4823	0.0104	470.1	0.0138	0.0152	0.0038	13.02	0.575
Veh_J	FTP	C	1.50	0.1105	0.0230	0.4263	0.0104	473.1	0.0188	0.0206	0.0043	13.07	0.640
Veh_J	FTP	C	1.50	-1.5018	0.0228	0.4816	0.0114	469.1	0.0189	0.0207	0.0046	12.96	0.818
Veh_J	FTP	C	1.50	-1.3139	0.0214	0.4330	0.0119	471.6	0.0177	0.0194	0.0042	13.03	0.425
Veh_J	FTP	C	1.50	-1.9733	0.0236	0.4293	0.0126	474.9	0.0195	0.0214	0.0043	12.88	1.028
Veh_J	FTP	D	1.41	-2.1218	0.0172	0.4220	0.0113	466.3	0.0143	0.0163	0.0028	13.19	0.820
Veh_J	FTP	D	1.41	-0.5335	0.0189	0.3512	0.0142	465.8	0.0165	0.0188	0.0030	12.78	0.347
Veh_J	FTP	D	1.41	-2.5160	0.0188	0.3998	0.0108	470.5	0.0165	0.0188	0.0029	13.31	0.485
Veh_J	FTP	D	1.41	2.0850	0.0212	0.3545	0.0121	471.4	0.0174	0.0198	0.0032	13.33	0.813
Veh_J	US06	A	2.72	-0.0666	0.0149	8.0578	0.0089	518.9	0.0080	0.0083	0.0079	14.63	
Veh_J	US06	A	2.72	-0.0581	0.0121	7.9107	0.0051	518.8	0.0063	0.0065	0.0066	14.62	1.138
Veh_J	US06	A	2.72	-0.0745	0.0070	5.3027	0.0060	513.2	0.0043	0.0044	0.0032	14.35	0.708

Vehicle	Cycle	Fuel	Fuel_PMI	IWR	THC g/mi	CO g/mi	NOX g/mi	CO2 g/mi	NMHC g/mi	NMOG g/mi	CH4 g/mi	CBFE mi/gal	PM mg/mi
Veh_J	US06	A	2.72	-0.0841	0.0144	9.7906	0.0051	510.3	0.0077	0.0079	0.0077	14.47	0.648
Veh_J	US06	A	2.72	-0.0734	0.0118	8.1209	0.0069	506.6	0.0062	0.0064	0.0064	14.29	0.587
Veh_J	US06	A	2.72	-0.0821	0.0137	11.9353	0.0093	512.9	0.0078	0.0081	0.0068	14.63	0.700
Veh_J	US06	B	1.53	-0.0760	0.0159	9.9582	0.0054	505.2	0.0089	0.0091	0.0081	14.06	0.648
Veh_J	US06	B	1.53	-0.0973	0.0063	7.4578	0.0071	503.2	0.0025	0.0026	0.0043	14.17	0.193
Veh_J	US06	B	1.53	-0.0976	0.0102	8.4625	0.0066	503.5	0.0056	0.0058	0.0052	14.22	0.366
Veh_J	US06	B	1.53	-0.0946	0.0119	6.3799	0.0071	501.7	0.0070	0.0072	0.0057	14.08	0.575
Veh_J	US06	Base	1.49	-0.0809	0.0198	10.0105	0.0062	506.6	0.0114	0.0118	0.0096	14.44	0.301
Veh_J	US06	Base	1.49	-0.0927	0.0160	8.5324	0.0095	503.0	0.0101	0.0104	0.0068	14.01	0.517
Veh_J	US06	Base	1.49	-0.1135	0.0144	9.0413	0.0059	500.0	0.0077	0.0079	0.0077	14.22	
Veh_J	US06	Base	1.49	-0.0892	0.0117	7.8029	0.0063	503.9	0.0066	0.0068	0.0058	14.27	0.762
Veh_J	US06	C	1.50	-0.0890	0.0162	10.5013	0.0057	508.4	0.0074	0.0076	0.0101	14.48	0.957
Veh_J	US06	C	1.50	-0.1078	0.0148	7.0049	0.0057	499.7	0.0068	0.0071	0.0092	14.09	0.300
Veh_J	US06	C	1.50	-0.1061	0.0140	8.2653	0.0062	507.5	0.0068	0.0071	0.0067	14.35	0.354
Veh_J	US06	C	1.50	-0.1044	0.0166	11.1954	0.0068	500.8	0.0079	0.0081	0.0099	14.04	0.501
Veh_J	US06	D	1.41	-0.0989	0.0163	6.1858	0.0058	500.2	0.0095	0.0098	0.0077	14.40	1.365
Veh_J	US06	D	1.41	-0.0820	0.0112	3.9795	0.0066	500.5	0.0066	0.0068	0.0053	13.88	1.031
Veh_J	US06	D	1.41	-0.0999	0.0126	6.9882	0.0059	507.9	0.0069	0.0071	0.0066	14.66	0.398
Veh_J	US06	D	1.41	-0.1011	0.0096	5.3893	0.0055	506.6	0.0061	0.0063	0.0039	14.55	0.248