Tier 3 Certification Fuel Impacts Test Program

United States Environmental Protection Agency

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1. Executive Summary

The U.S. Environmental Protection Agency (EPA) has the responsibility to determine the test procedures to be used when performing emission and fuel economy testing for vehicles and engines. Part of this responsibility involves defining the properties of the test fuels that are required for the testing performed by manufacturers and laboratories, and also providing the proper analytical equations to calculate both emission and fuel economy for the test fuels. When test fuel properties change, as they have recently for the Tier 3 vehicle emissions program, EPA must make the proper test procedure adjustments to maintain the intended level of stringency for existing or new emission and fuel economy (FE) standards. The test procedure adjustments include changes to the method of calculating the emission and FE results that are subject to applicable standards. To determine the appropriate test procedure adjustments from the changes to the test fuel properties included in the Tier 3 program, the agency performed a study on eleven vehicles operating over the two required test cycles using the two test fuels, the Tier 2 and the new Tier 3 test fuel. The overall results across the test fleet showed a reduction in CO_2 of 1.78% for the FTP and 1.02% for the HFET tests for Tier 3 compared to Tier 2 test fuel. For fuel economy the overall reduction was 1.76% for the FTP and 2.42% for the HFET tests for Tier 3 compared to Tier 2 test fuel. Throughout, the high levels of statistical significance observed, both for CO_2 and fuel economy, suggest that the measured differences in these parameters are actual and in reasonable agreement with the difference projected during the planning of the study.

2. Introduction / Purpose

EPA adopted a new set of “Tier 3” fuel and motor vehicle emission standards in 2014 to reduce air pollution.[1] The Tier 3 emission standards include changes to several properties of emission test fuel to make it more representative of in-use fuel, and some of these changes are expected to affect emissions and fuel economy. Among the property changes as specified in Section 3.1 below, the property changes of interest for greenhouse gas (GHG) emissions and fuel economy included total aromatics, aromatics distribution and ethanol content. This test program was initiated to compare Tier 2 certification fuel, the fuel on which the Phase 1 and Phase 2 GHG and Corporate Average Fuel Economy (CAFE) standards were established for light-duty and heavy duty-vehicles, with the new Tier 3 certification fuel from the Tier 3 program. The program results will be used as a basis for test procedure adjustments to ensure consistent stringency of GHG and fuel economy standards as vehicle certification makes the transition to Tier 3 test fuel.

[1] For additional information on the light-duty Tier 3 program, see https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-amendments-related-tier-3-motor-vehicle

3. Study Design

To determine the impact of the new Tier 3 fuel on GHG emissions and fuel economy, we designed a study that would test vehicles with the most recent technologies deployed in vehicles presently available to consumers. These technologies have largely been implemented in gasoline vehicles to reduce GHG emissions and improve fuel economy in response to more stringent GHG and fuel economy standards. The study was designed to test these vehicles while operating on the Tier 2 gasoline certification fuel, which was the fuel used to determine the stringency levels when the 2017 to 2025 GHG and CAFE standards were finalized, and then test the same exact vehicles while operating on the Tier 3 certification fuel finalized in the Tier 3 rule. The GHG and fuel economy results of each vehicle in the test program on the two different test fuels would then have a statistical analysis performed to determine the impact of the fuel change on CO_2 and fuel economy that is to be expected on these advanced technology vehicles when the required GHG and CAFE test fuel becomes Tier 3 fuel in model year 2020 and later. Unless otherwise specified, the term fuel economy in this analysis refers to the carbon balance result, not the adjusted CAFE value.

3.1. Test Fuels

The two test fuels used to generate the emission and fuel economy results in this study were Tier 2 EEE and Tier 3 regular grade. Both fuels were dispensed from underground tanks through the conditioning and metering system at the EPA National Vehicle and Fuel Emission Laboratory (NVFEL). The Tier 2 fuel was the same fuel used daily for ongoing certification and in-use surveillance programs at NVFEL. The Tier 3 fuel was procured for use in validating test methods and emission calculations in anticipation of its phase-in as the required test fuel. Table 3.1 summarizes the test fuel properties, with more detailed data available in Appendix A. Both fuels met their respective regulatory specifications, also available in Appendix A.

Regulatory fuel economy calculations include measured values for three fuel properties: specific gravity, carbon weight fraction, and net heat of combustion. ASTM publishes reproducibility values for the test methods, which are determined by performing statistical analysis on tests of the same sample made over a period of time by different operators in different locations. This value represents the variability inherent in the test method and can be used as a guide as to whether two different test results indicate an actual difference in the sample. Specific gravity (SG) by ASTM D4052 has a small ASTM reproducibility value relative to the other two fuel property methods. At least two SG test results were obtained for each fuel to produce the average used in the analysis. For the other two properties, test results from at least four laboratories were combined into an average value. After collecting all test results, relative standard deviation (RSD), defined as the standard deviation divided by the mean, among the labs was found to be 0.5% or less for each fuel property.

Carbon weight fraction (CWF) values used in this study were derived from percent mass results by ASTM D5291. This method combusts a small sample of fuel and measures the gaseous products. It was developed for diesel and other low-volatility fuels but can be run for gasoline by a skilled operator, and several labs produce acceptable results. This method also reports hydrogen content, but not oxygen. The Tier 2 test fuel contains negligible oxygen so interpreting D5291 results is straightforward and all labs reported C+H sums falling with the range 99-101%. For oxygenated fuels, such as Tier 3 test fuel, D5291 results are typically normalized to 100% using oxygen content determined by D5599 or D4815. Thus, since the Tier 3 CWF relied on oxygen data, we obtained three oxygen content measurements by D5599. These were averaged, and that average was used to normalize each lab's Tier 3 CWF value, with those results then being averaged to produce the CWF result used in the fuel economy analysis.

Net heat of combustion (or net heating value, NHV) for both test fuels was determined according to ASTM D4809. This method combusts a small sample inside an oxygen-purged calorimeter and reports gross heat of combustion (C_v) as the direct results, with an equation to convert the result to NHV (C_p) using mass percent hydrogen in the sample. This step was carried out individually for each lab using its D5291 result for hydrogen, after which the NHVs were averaged to produce the final value used in the fuel economy analysis. Comparing the two test fuels, we see Tier 3 fuel has 3.46% less energy on a mass basis, or 2.77% less on a volumetric basis, than Tier 2 fuel. In terms of carbon intensity, Tier 3 fuel has 1.33% less carbon per unit energy.

Table 3.1: Test fuel properties.

Parameter	Tier 2	Tier 3	Units	ASTM Method
Initial Boiling Point	89	100		
T10	126	129		
T50	223	210	°F	
T90	317	322		
Final Boiling Point	406	387		D86
Recovery	97.5	97.3		
Residue	1.1	0.9	vol %	
Loss	1.4	1.8		
Specific Gravity, 60°F	0.7437 [a]	0.7490 [a]	-	D4052
Density, 60°F	0.7430 [a]	0.7482 [a]	g/cm^3	
DVPE (EPA equation)	9.0	8.8	psi	D5191
Ethanol	0.0	10.15	vol %	
Oxygenates other than EtOH	0.0	0.0		D5599
Oxygen	0.0	3.7 [a]		
Carbon	86.8 [a]	82.7 [a]	mass %	D5291
Hydrogen	13.2 [a]	13.6 [a]		
Carbon	86.6	82.6	mass %	D3343
Hydrogen	13.4	13.7		
Sulfur	39.6	8.3	mg/kg	D2622
Aromatics	30.6	22.9		
Olefins	0.6	5.4		D1319
Saturates	68.8	71.7	vol %	
Aromatics	32.3	23.8		D5769
Water Content	70	930	mg/kg	E1064
Research Octane Number	96.5	91.0	-	D2699
Motor Octane Number	88.7	83.5	-	D2700
AKI (R+M)/2	92.6	87.3	-	D2699/2700
Net Heat of Combustion	18,446	- [b]	Btu/lb	D3338
Net Heat of Combustion, 25°C	18,529 [a]	17,889 [a]	Btu/lb	D4809
Net Heat of Combustion, 25°C	114,870	111,689	Btu/gal	Calculated
Carbon Intensity	21,252	20,968	gC/MMBtu	Calculated

[a] Value is an average of measurements from multiple laboratories.
[b] Method is not valid for oxygenated fuels.

3.2. Vehicles

EPA selected a set of test vehicles that represent a variety of technologies likely to be used to meet the GHG emission and fuel economy standards in the future. Eleven vehicles, described in Table 3.2, are included in the analysis of this test program. Most were acquired by EPA's National Center for Advanced Technology (NCAT) to help validate EPA's Advanced Light-duty Powertrain and Hybrid Analysis (ALPHA) model, a full-vehicle simulation tool for predicting fuel economy and CO_2 emissions. The ALPHA model was central to the 2017-2025 Light-Duty CAFE and GHG Emission Standards rulemaking. Just over half are vehicles with Gasoline Direct Injection (GDI) engines which enables higher compression ratio for improved fuel efficiency and combustion control. This technology approach to improving FE and GHG emissions has been adopted by several manufacturers and is prevalent in a large portion of the fleet today. Some of the vehicles are equipped with downsized turbocharged engines. This technology is most prevalent in light-duty cars and trucks produced by Ford and is also used in the Volvo S60 T5, the Honda Civic as well as the Ford F150 in this program. The Mazda 3 uses a naturally aspirated high compression engine with a high degree of valve timing authority in order to operate as an Atkinson Cycle engine when required. The use of this technology is starting to increase as it can be found in several models currently entering the market and in the future plans of other vehicles. The Silverado 1500 pickup truck uses cylinder deactivation technology which is also popular in several larger engine displacement models from various manufacturers. When cruising, the six cylinders deactivate down to using only five, four and even three cylinders to propel the vehicle down the road. This technology has been popular in certain larger vehicles such as the GM Silverado pick-up which uses the GM Active Fuel Management (formerly known as Displacement on Demand or DoD) to deactivate cylinders when they are not needed resulting in reductions in emissions and fuel usage. The Ram has stop-start technology and an 8-speed automatic transmission. Transmissions are moving to a higher number of gears for greater efficiencies in the future, even going to 9 and 10 speeds. The stop-start feature reduces time the engine spends idling such as at traffic lights and in traffic jams, which can reduce fuel consumption and emissions. The Altima and the Civic in this program both have Continuously Variable Transmissions (CVT), which varies the ratio while the engine stays at the most efficient RPM window, allowing for greater fuel efficiency. A heavy-duty Class 2b truck, the Chevrolet Silverado 2500, was also tested in the program to determine whether heavy-duty gasoline engines are likely to show an effect similar to light-duty vehicles.

Table 3.2: Test vehicle information.

Model Year	Vehicle Make/Model	Engine	Odometer Miles	Technologies
2014	Ram 1500	3.6L V6 PFI	5,300	8 speed automatic transmission, start-stop disabled
2016	Acura ILX	2.4L I4 GDI	4,100	8 speed DCT with a torque converter
2013	Nissan Altima	2.5L I4 PFI	8,700	CVT
2016	Honda Civic	1.5L I4 GDI	9,000	CVT, downsized turbocharged engine
2015	Ford F150 Eco-Boost	2.7L V6 GDI	7,600	Downsized turbocharged engine, start-stop disabled
2013	Chevrolet Malibu	2.4L I4 GDI	8,900	
2016	Chevrolet Malibu	1.5L I4 GDI	5,400	Downsized turbocharged engine
2014	Mazda 3	2.0L I4 GDI	16,300	High compression ratio engine
2014	Chevrolet Silverado 1500	4.3L V6 GDI	8,700	Cylinder deactivation
2015	Volvo S60 T5	2.0L I4 GDI	8,000	Downsized turbocharged engine
2016	Chevrolet Silverado 2500	6.0L V8 PFI	14,600	Class 2b truck

3.3. Emission Test Design

3.3.1. Test Cycles

The emission tests were conducted on a chassis dynamometer using the drive cycles required for certification of the light-duty GHG emission and corporate average fuel economy standards. The vehicles were tested on both fuels over the Federal Test Procedure (FTP) and Highway Fuel Economy (HFET) certification test cycles. The speed versus time schedule for these cycles are shown in Figures 3.3.1 and 3.3.2.

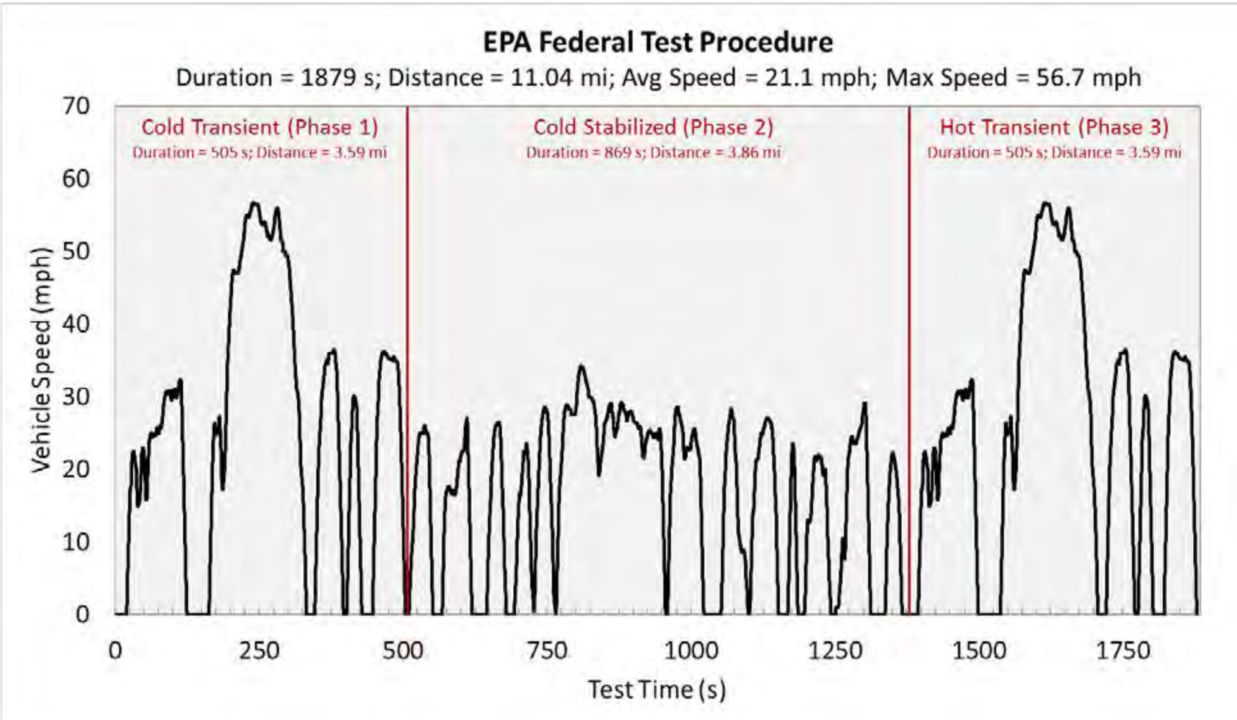

Figure 3.3.1. EPA FTP test cycle speed vs. time profile.

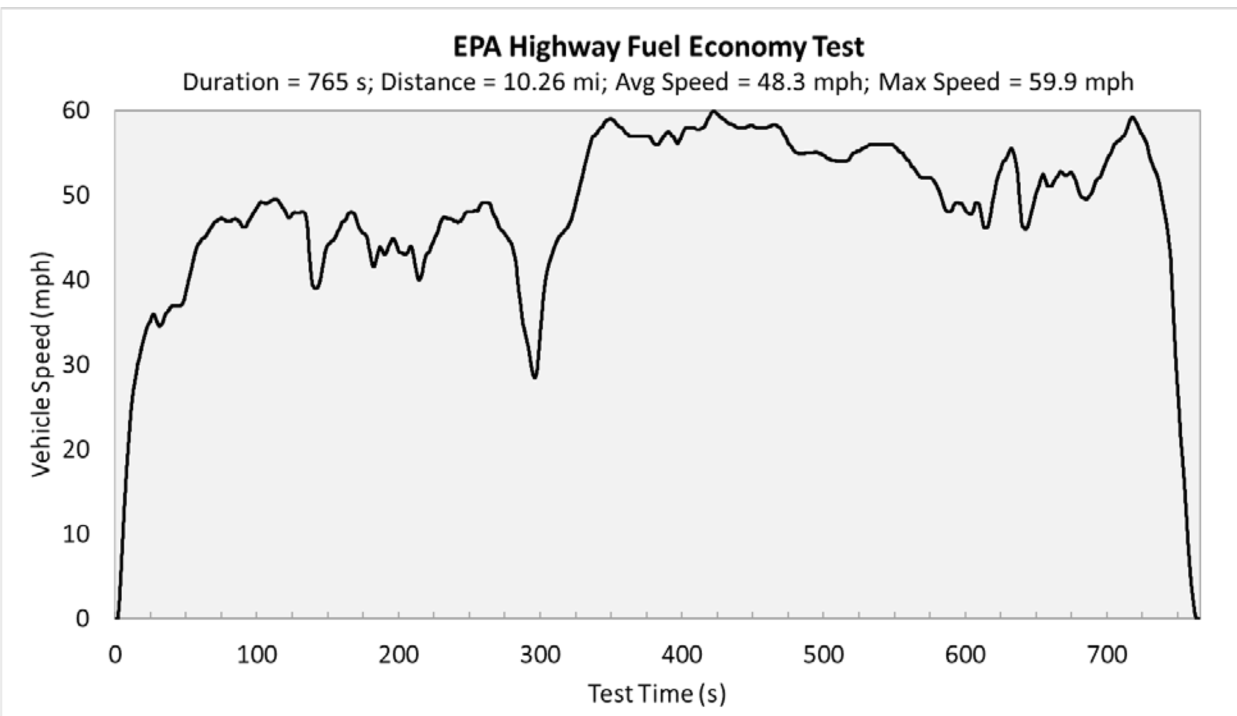

Figure 3.3.2. EPA HFET test cycle speed vs. time profile.

3.3.2. Test Site and Emission Measurements

The test site used for this study is compliant with 40 CFR part 1066 requirements for regulated gaseous and particulate measurements. Table 3.3 gives information on the test site equipment. The focus of the study was primarily on fuel economy and carbon dioxide (CO_2), a GHG which is also the most important emission input for the fuel economy calculation. Methane (CH_4) was measured for all tests, but due to an analyzer malfunction some tests on the Civic and Silverado 1500 are missing measured values. The median emission value from similar tests on the same vehicle was substituted for the missing values when fuel economy was calculated. These values are shown in Appendix D. Overall this is a tiny adjustment, as methane emission rates fall below 0.005% of CO_2 across the dataset. Measurement of N_2O was also initiated but ongoing equipment problems resulted in unreliable results for most tests, therefore an analysis of the N_2O emissions impact from the fuel could not be performed. Other pollutants including total hydrocarbons (THC), methane (CH_4), nonmethane organic gases (NMOG), carbon monoxide (CO), oxides of nitrogen (NO_X), and particulate matter (PM as $PM_{2.5}$) were also measured or calculated.

Fuel economy was calculated as shown in Equation 3.1, which is the carbon-balance form of the equation being proposed by EPA for use with Tier 3 test fuel.[2] While this equation is specified for low-level ethanol blends, it was applied to both test fuels for the results reported here in order to provide as precise a comparison as possible.

$$FE = \left[\frac{CWF_{fuel} \cdot SpecificGravity_{fuel} \cdot 3781.7}{CWF_{exh} \cdot NMOG + 0.749 \cdot CH_4 + 0.429 \cdot CO + 0.273 \cdot CO_2} \right] \qquad \text{Eq. 3.1}$$

NMOG values were determined using the calculation method described 40 CFR 1066.635(c) for each emission phase (bag), then the FTP composite value was determined using the typical emission weighting factors.[3] The carbon weight fraction (CWF) of exhaust was assumed to be the same as that of the fuel, consistent with current certification practices.

[2] The carbon-balance form does not attempt to adjust results back to a baseline fuel using NHV. This Tier 3 version also uses NMOG+CH_4 in place of THC emissions to better account for combustion products of oxygenated fuels.
[3] The weighting factors are 0.43 for the cold transient phase (bag 1), 1.0 for the cold stabilized phase (bag 2), and 0.57 for the hot transient phase (bag 3).

Table 3.3: Test site equipment.

Test site	**40 CFR part 1066 compliant.**
Dynamometer	**MAHA medium duty 48" roll 4WD dynamometer capable of testing up to 20,000 lbs GVWR single and dual drive axle vehicles**
CVS	**8" diameter dilution tunnel with tailpipe pressure control, heated dilution air capability, and HEPA filtration; Horiba CVS-7200T flow control utilizing four critical flow venturis capable of 15 flow rates up to 1200 CFM**
Test cell host	**Horiba CDTCS 5000**
Gaseous analytical equipment	**Horiba MEXA-ONE C1 and D1 dilute and raw benches that measure CO, CO2, THC, CH4, NOx, and N2O (dilute only)**
PM equipment	**Horiba MEXA-ONE PM consisting of three sample trains to allow measurement of 3 samples simultaneously**

All analyzer checks were performed according to 40 CFR part 1066 specifications. There were several calibration and maintenance activities conducted in the test site including, but not limited to the following:

- Daily: bag leak checks[4], air handling system tests, and zero spans.
- Weekly: repeatable car checks[5], coastdowns for MAHA 2WD and 4WD dynamometer[6], Dynamometer Parasitic Losses Verification[7], Gravimetric Propane Injection for THC[8], Vehicle Sampling Analysis Correlations for bag checks on CO, CO_2, CH_4, NO_x.[9]
- Every 35 days: CH_4 Gas Chromatography column efficiency check, NOx converter check, chemiluminescent detector CO_2 + H_2O Quench Check, MEXA-ONE analyzer linearizations per Horiba instructions and linearity checks per 40 CFR part 1066.
- Typically, annually: FID O_2 inference check, FID response factor check, and NDIR interference checks.

3.4. Test Procedures

The test program was designed to develop datasets that could distinguish small differences in CO_2 emissions and fuel economy between the two fuels. Special efforts were taken to reduce

[4] EPA National Vehicle Fuel and Emissions Laboratory Work Instructions WI-1029
[5] EPA National Vehicle Fuel and Emissions Laboratory Work Instructions WI-1262
[6] EPA National Vehicle Fuel and Emissions Laboratory Work Instructions WI-1109
[7] EPA National Vehicle Fuel and Emissions Laboratory Work Instructions WI-1078
[8] EPA National Vehicle Fuel and Emissions Laboratory Work Instructions WI-1269
[9] EPA National Vehicle Fuel and Emissions Laboratory Work Instructions WI-1199

test-to-test variability with a minimum number of tests. The procedures were designed with the goal of completing testing of one vehicle on one fuel in a single work week. However, there were instances when additional testing was required so that testing extended to an additional week. We attempted to utilize the same test site and driver throughout the program across all fuels and vehicles to reduce site-to-site and driver variability but a subset of the tests was conducted with a different driver. In addition, the fuel order was reversed for the second half of the vehicles to avoid any potential fuel-order bias. As shown in Tables 3.5.4 and 3.5.5, approximately half of the vehicles were tested first with the Tier 2 fuel and then with the Tier 3 fuel.

The fuel preparation procedures, as shown in Table 3.4.1, were outlined prior to testing to ensure that the fuel was completely flushed and the vehicle control systems appropriately adapted to the new fuel. For each fuel change, a triple drain and fill procedure was used to completely flush out the previous fuel. Prior to testing, each vehicle ran three LA4 cycles, defined as the first two phases of the FTP, to allow for the engine to adapt to the new fuel properties, including ethanol.

The emissions testing followed the procedures laid out in Table 3.4.2. Two changes were implemented during the program to further reduce the testing variability. A plug-in trickle charger was used to keep the battery on the vehicle completely charged during the soak times over the weekend and each overnight soak. In addition, we made an adjustment to run the same test sequence and number of tests each day. At the beginning of the program we maximized the number of tests run in a day, but this led to a different number of tests conducted on a daily basis. We observed a higher variability with this approach. Therefore, we then required the same sequence on each day and the test data became more repeatable.

In addition to the procedures in Table 3.4.2, weekly background and dilution air checks were also run throughout the program to maintain integrity of the data and to understand the variables in case of fluctuating measurements. These were within normal range and did not appear to affect the data. The test cell conditions such as temperature, pressure and relative humidity were monitored and remained stable throughout the program per 40 CFR parts 1065 and 1066 requirements.

The complete valid dataset can be found in Appendix B in chronological order for each vehicle. We did experience some additional issues which resulted in excluded tests, which are shown in Appendix C. The issues included the following:

- PM filer holder issue during HFET testing: The first two PM filter holders were being left open while sample collection occurred on the fourth filter. Since the system was pulling airflow through all filters this resulted in an unknown error on all gaseous emissions. Therefore, it was necessary to repeat all HFET tests conducted in the first portion of the program until the situation was fixed.
- Modal bench malfunction: A modal bench malfunction caused an error in the calculated results for the gaseous bag emissions which resulted in invalid tests for the Ram and the first Malibu (Malibu 1).

- Inconsistent Acura results: The initial HFET data for the Acura showed no clear effect of the test fuel, which was inconsistent with the FTP results. We added a controlled experiment with additional replicates comparing the fuels and the result suggested an opposite fuel effect. This latter experiment used a different driver, and we did not want to mix data from different drivers so we used only the newer data in the overall analysis. Later tests with Tier 3 premium fuel indicated an effect of octane on CO_2 emissions, which could explain the opposite fuel effect observed with Tier 3 regular fuel. However, the Tier 3 premium data was not included in the overall analysis or this report. This is further discussed in Section 5.
- Inconsistent Altima results: The Altima initial HFET tests were repeated at a later time because of the filter holder issue. In this later experiment, the initial fuel effect was inconsistent with the FTP results so a decision was made to conduct additional confirmatory tests. The first data of testing with the first fuel showed a large spread with descending CO_2 values. With further investigation we realized the trickle charger had not been on the vehicle during several weeks of vehicle non-use prior to these additional tests. After ensuring the vehicle battery was charged, another test set was performed. This final set was retained in the dataset.
- Inconsistent Malibu 1 results: The initial HFET tests for the first Malibu were also repeated at a later time because of the filter holder issue. Again, we saw an inconsistent trend as compared to the FTP data. These tests also had some repeatability issues. This vehicle had been used by another testing group and had been returned to us with a fault code. Necessary actions were taken to resolve any issues before an additional test set was performed. This final data set was retained in the dataset.
- Inconsistent Silverado results: The initial Silverado HFET data showed no clear effect of test fuel, which was inconsistent with the FTP results. An additional set of data with both fuels was collected and confirmed the original results from the first dataset. Since a different driver was used and we wished to keep to our resolve of not mixing drivers, only the newer data was used in the analysis.

Table 3.4.1: Fuel change procedure.

Step	Description
1	**With the ignition key in OFF position, drain vehicle fuel completely via installed fuel drain or the fuel rail.** Note: Contact project engineer for additional instructions if the vehicle has a saddle tank and does not have the fuel drain installed.
2	**Turn vehicle ignition to RUN position for 30 seconds to allow the fuel level reading to stabilize. Confirm the return of fuel gauge reading to zero.**
3	**Turn ignition off. Fill fuel tank to 50% with next test fuel in sequence. Fill-up fuel temperature must be less than 60°F.**
4	**Repeat Steps 1-3. (If repeated steps 1-3, move to Step 5)**
5	**Repeat Steps 1-3, but fill the fuel tank to 100%.**
6	**Fully warm up the vehicle and run three sampled LA4 prep cycles (gaseous emissions only), with key-off after every test.**
7	**Run vehicle coastdowns following the 3 LA4 prep cycles.**
8	**Allow the vehicle to idle in neutral for two minutes, then shut the engine down in preparation for the soak. Report results of those tests to project engineer.**
9	**Move vehicle to soak area without starting the engine (or can leave on dyno for soak).**
10	**Park vehicle in soak area at proper temperature (75 °F) for no more than 100 hours.** Note: During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device. Note: If 100-hour soak time is exceeded before Step 3 of the Vehicle Test Protocol is executed, drain the fuel tank and fill it to 100% with the same fuel the following Friday, then repeat Steps 7 and 8.

Table 3.4.2: Vehicle test procedure to be performed during one work week.

Step	Description
1	**Move the vehicle to an appropriate area and without starting the engine take an 8 oz. sample of fuel from the fuel rail. Submit the sample to the Chemistry Lab for the measurement of density at 60ºF by ASTM D4052 and ethanol content by ASTM D5599. Request that results be available within 24 hours, if possible.** Note: Make sure the label on the fuel container includes vehicle designation, fuel FTAG number and date sample was taken.
2	**Move vehicle to test area without starting engine.**
3	**Perform a sampled FTP test followed by a sampled HFET test and a sampled US06 test.**
4	**Move vehicle to soak area without starting the engine (or can leave on dyno for soak).**
5	**Park vehicle in soak area at proper temperature for 12-52 hours.** Note: During the soak period, maintain the nominal charge of the vehicle's battery using an appropriate charging device. Note: If the 52-hour soak time limit is exceeded or if there is no chance to complete Steps 6 and 7 in the course of the same week, drain the fuel tank and fill it to 100% with the same fuel the following Friday, then repeat Steps 7 and 8 of the Fuel Change and Vehicle Preparation Procedure.
6	**Move vehicle to test area without starting the engine.**
7	**Repeat Steps 3-5 until the required number of replicates is met.**

3.5 Prospective Power Analyses

In the implementation of the project an important consideration concerned the number of replicate tests required for each vehicle for each cycle. Rather than performing a pre-determined number of replicates, decisions were made dynamically, based on estimates of statistical power to detect a difference in CO_2 emissions between the two fuels on each vehicle. The precision goal for FTP cycle data from each vehicle was to detect an effect of 1.5%, with 80% power at a 95% confidence level. However, in some cases the results achieved differed from the target due to logistical issues involving test-site and vehicle availability. The estimated effect size of 1.5%

was based on the CO_2 model from the EPAct/V2/E-89 study and typical certification fuel properties.[10]

For each vehicle, we performed three initial replicates on the first test fuel selected. We then calculated power to detect the specified effect size, based on the observed variance and the mean of the first three replicates, assuming that the variance of three replicates on the second test fuel would equal that of the first fuel. If the power was below the target, an additional replicate test was performed, and this process repeated until the target was met. At this point the fuel was changed and the process was repeated on the second fuel until the target power was achieved using the actual variance values.

For the majority of vehicles, the numbers of HFET replicates matched those on the FTP cycle, as these tests were conducted in pairs. A subset of vehicles required additional HFET replicates to confirm or replace tests where procedural or equipment problems occurred.

The calculation was performed as for a one-tailed two-sample test, under an assumption of equal variances. We followed a one-tailed assumption because we thought it reasonable to expect a reduction in CO_2 emissions on the Tier 3 fuel, due primarily to its lower aromatics level.

To estimate power, we assigned the acceptance region under the null hypothesis, as defined by its upper and lower confidence limits, calculated as shown in Eq. 3.5.1

$$\text{acceptance region} = 0 \pm t_{0.95, n_{T2}+n_{T3}-2} s_{\text{difference}} \qquad \text{Eq. 3.5.1}$$

where the standard error of the difference is defined as

$$s_{\text{difference}} = s_{\text{pooled}} \sqrt{\frac{1}{n_{T2}} + \frac{1}{n_{T3}}} \qquad \text{Eq. 3.5.2}$$

In estimating the standard error, the pooled variance for the difference in means is defined as

$$s^2_{\text{pooled}} = \frac{(n_{T2}-1)s^2_{T2} + (n_{T3}-1)s^2_{T3}}{n_{T2}+n_{T3}-2} \qquad \text{Eq. 3.5.3}$$

where:

n_{T2} = number of replicates on the Tier 2 fuel,
n_{T3} = number of replicates on the Tier 3 fuel,
s_{T2} = standard deviation of replicate measurements on the Tier 2 fuel, and
s_{T3} = standard deviation of replicate measurements on the Tier 3 fuel.

The test statistics for the acceptance region, representing lower and upper confidence limits under the null hypothesis, were then calculated with reference to the assumed difference under the alternative hypothesis, as shown in Eq. 3.5.4,

[10] Memo to Tier 3 final rulemaking docket by James Warila, February 28. 2013. Docket entry number EPA-HQ-OAR-2011-0135-0605.

$$t_{\text{lower}} = \frac{\text{CL}_{\text{lower}} - \left(-0.015 x_{\text{1st-fuel}}\right)}{s_{\text{difference}}}, \quad t_{\text{upper}} = \frac{\text{CL}_{\text{upper}} - \left(-0.015 x_{\text{1st-fuel}}\right)}{s_{\text{difference}}} \qquad \text{Eq. 3.5.4}$$

with the standard error of the difference defined as above.

The probability of accepting the null hypothesis when it is false (Type-II error) was then estimated as the probability that the actual test result would fall in the acceptance region. This probability is defined as shown in Eq. 3.5.5.

$$\beta = \Pr\{ t_{\text{actual}} > t_{\text{lower}} \text{ and } t_{\text{actual}} < t_{\text{upper}} \} \qquad \text{Eq. 3.5.5}$$

In cases where both t_{lower} and t_{upper} were of the same sign, either positive or negative, β was calculated as the difference in probabilities for the lower and upper *t*-statistics.

If t_{lower} and t_{upper} were both negative, β was estimated as

$$\beta = abs(\Pr\{t < t_{\text{upper}}\} - \Pr\{t < t_{\text{lower}}\}) \qquad \text{Eq. 3.5.6}$$

However, if t_{lower} and t_{upper} were both positive, β was estimated as in Eq. 3.5.7.

$$\beta = abs(\Pr\{t > t_{\text{lower}}\} - \Pr\{t > t_{\text{upper}}\}) \qquad \text{Eq. 3.5.7}$$

In both cases, power for the test was calculated simply as 1-β.

However, if t_{lower} and t_{upper} were of opposite sign, power was calculated directly as the sum of the probabilities for the lower and upper *t*-statistics.

Specifically, if $t_{\text{lower}} < 0$ and $t_{\text{upper}} > 0$, power was estimated as

$$1 - \beta = \text{power} = \Pr\{t < t_{\text{lower}}\} + \Pr\{t > t_{\text{upper}}\} \qquad \text{Eq. 3.5.8}$$

But if $t_{\text{lower}} > 0$ and $t_{\text{upper}} < 0$, power was estimated as

$$1 - \beta = \text{power} = \Pr\{t < t_{\text{upper}}\} + \Pr\{t > t_{\text{lower}}\} \qquad \text{Eq. 3.5.9}$$

In all cases, the degrees of freedom for test statistics were given as $n_{T2}+n_{T3}-2$.

Power results for tests on the FTP and HFET test cycles are shown in Tables 3.5.4 and 3.5.5, respectively. For the FTP cycle, calculated power exceeded the target level for all vehicles. For the HFET cycle, power was below the target for two vehicles, but exceeded the target for the remaining nine vehicles. For most vehicles, three replicates on each fuel proved adequate to achieve the target power level. However, in some cases, up to six replicates were performed on one of the fuels.

Table 3.5.4: FTP Cycle: Prospective power analyses for CO_2 emissions, by vehicle.

Vehicle	first fuel	Mean[1] (g/mi)	Difference (H_a) [2] (g/mi)	Replicates n_{T2}	Replicates n_{T3}	Standard Deviations T2	Standard Deviations T3	Margin-of-error[3] (g/mi)	*t*-values: acceptance region lower	*t*-values: acceptance region upper	*p*-values: acceptance region lower	*p*-values: acceptance region upper	*β*	Power
Acura	T2	275.66	-4.135	4	3	1.7579	1.4539	2.5287	1.280	5.310	0.128	0.002	0.12679	0.8732
Altima	T2	276.19	-4.143	3	5	0.9739	1.0967	1.5004	3.422	7.308	0.007	0.0002	0.00689	0.9931
Malibu 1	T2	314.53	-4.718	3	3	0.5403	0.7474	1.1351	6.729	10.993	0.001	0.0002	0.00108	0.9989
Mazda	T2	242.12	-3.632	3	3	1.2054	0.4800	1.5969	2.717	6.980	0.027	0.001	0.02548	0.9745
Ram	T2	423.94	-6.359	6	3	1.8872	3.7524	3.4330	1.615	5.404	0.075	0.001	0.07469	0.9253
Volvo	T2	305.98	-4.590	6	3	1.7998	0.4699	2.0653	2.316	6.105	0.027	0.0002	0.02662	0.9734
Civic	T3	213.37	3.201	3	3	0.8475	0.5022	1.2124	-7.759	-3.496	0.001	0.012	0.01175	0.9882
F150	T3	376.87	5.653	3	3	1.4747	1.5390	2.6235	-6.725	-2.462	0.001	0.035	0.03351	0.9665
Malibu 2	T3	268.64	4.030	3	5	0.4382	0.8567	1.0555	-9.362	-5.475	0.00004	0.001	0.00073	0.9993
Silverado	T3	419.88	6.298	3	6	1.5009	2.5931	3.1265	-5.711	-1.922	0.0004	0.048	0.04766	0.9523
Silverado (2b)	T3	706.83	10.60	3	3	0.5384	0.8865	1.2766	-19.84	-15.57	0.00002	0.00005	0.00003	1.0000

[1] Mean FTP cycle aggregate result on the first fuel tested.
[2] Expected difference under the alternative hypothesis, calculated as 1.5% of the mean on the first fuel.
[3] Calculated as the product of the critical *t*-statistic, for 95% confidence and $n_{T2}+n_{T3}-2$ degrees of freedom, and the standard error for the difference in means.

Table 3.5.5: HFET Cycle: Prospective power analyses for CO_2 emissions, by vehicle.

Vehicle	first fuel	Mean[1] (g/mi)	Difference (H_a) [2] (g/mi)	Replicates n_{T2}	Replicates n_{T3}	Standard Deviations T2	Standard Deviations T3	Margin-of-error[3] (g/mi)	*t*-values: acceptance region lower	*t*-values: acceptance region upper	*p*-values: acceptance region lower	*p*-values: acceptance region upper	*β*	Power
Acura	T2	171.31	-2.570	3	3	0.3619	0.3842	0.6496	6.301	10.565	0.002	0.0002	0.00139	0.99861
Altima	T2	165.49	-2.482	6	3	0.4796	1.1564	0.9903	2.855	6.644	0.012	0.0001	0.01211	0.98789
Malibu 1	T2	189.15	-2.837	3	4	2.3365	1.0493	2.5956	0.188	4.218	0.429	0.004	0.42509	0.57491
Mazda	T2	161.87	-2.428	3	3	0.5045	0.5376	0.9074	3.573	7.836	0.012	0.001	0.01094	0.98906
Ram	T2	262.76	-3.941	3	3	0.5913	1.2250	1.6743	2.887	7.150	0.022	0.001	0.02134	0.97866
Volvo	T2	175.61	-2.634	3	3	0.8586	1.6970	2.3408	0.267	4.531	0.401	0.005	0.39601	0.60399
Civic	T3	144.75	2.147	3	3	0.3345	0.6830	0.9361	-7.022	-2.758	0.001	0.025	0.02438	0.97562
F150	T3	244.79	3.629	3	3	1.5878	0.8544	2.2193	-5.618	-1.354	0.002	0.124	0.12112	0.87888
Malibu 2	T3	166.02	2.454	3	5	0.5799	0.8100	1.0519	-6.476	-2.589	0.0003	0.021	0.02030	0.97970
Silverado	T3	281.37	4.216	3	3	1.4616	0.6754	1.9817	-6.667	-2.403	0.001	0.037	0.03573	0.96427
Silverado (2b)	T3	447.66	6.647	3	3	1.7182	0.9522	2.4178	-7.992	-3.729	0.001	0.010	0.00950	0.99050

[1] Mean HWFET result on the first fuel tested.
[2] Expected difference under the alternative hypothesis, calculated as 1.5% of the mean on the first fuel.
[3] Calculated as the product of the critical *t*-statistic, for 95% confidence and $n_{T2}+n_{T3}-2$ degrees of freedom, and the standard error of the difference in means.

4. Results

This section describes and presents statistical analyses of the results for CO_2 and carbon-balance fuel economy. In addition to CO_2, the calculation of fuel economy involves the use of test results for several other species, including CO, THC, NMOG, and CH_4. Results for these species are not summarized in this section. However, we have included test results for each in Appendix D. For completeness, we have also included results for NO_x and PM.

As a counterpart to the prospective power calculations performed during testing to determine sample sizes for each vehicle, we performed tests of significance for each vehicle after the completion of testing.

As with the power calculations, the retrospective tests were performed as two-sample *t*-tests for differences in means. However, it is important to note that the retrospective analysis of results incorporated several important differences from the prospective power analyses:

- The retrospective tests were performed as two-tailed, rather than one-tailed tests. The prospective one-tailed assumption was revised due to the realization that increases in CO_2 emissions on the Tier 3 fuel were possible for some vehicles, although unlikely.
- The retrospective tests were performed assuming unequal, rather than equal variances. The unequal-variances assumption was adopted following observation of two- to three-fold differences in standard deviations for replicates on the two fuels for several vehicles. Consistent with this assumption, the degrees of freedom for each test were estimated using a Satterthwaite approximation, as described below.
- The difference in means is consistently calculated as the mean on Tier 3 fuel minus that on Tier 2 fuel ($\bar{x}_{T3} - \bar{x}_{T2}$), without respect to testing order.
- Tests were performed for carbon-balance fuel economy, as well as for CO_2 emissions.

Accordingly, the tests were formulated as follows:

Null hypothesis: H_0: $\bar{x}_{T3} - \bar{x}_{T2} = 0$

Alternative hypothesis: H_a: $\bar{x}_{T3} - \bar{x}_{T2} \neq 0$

Accordingly, the test statistic was calculated as shown in Eq. 4.1,

$$t_{\text{actual}} = \frac{(\bar{x}_{\text{T3}} - \bar{x}_{T2}) - 0}{\sqrt{\frac{s_{T2}^2}{n_{T2}} + \frac{s_{T3}^2}{n_{T3}}}} \qquad \text{Eq. 4.1}$$

where:

n_{T2} = number of replicates on the Tier 2 fuel,
n_{T3} = number of replicates on the Tier 3 fuel,
s_{T2} = standard deviation of replicate measurements on the Tier 2 fuel, and
s_{T3} = standard deviation of replicate measurements on the Tier 3 fuel.

Note that, consistent with the two-tailed assumption, the critical *t*-statistic for each test was the value corresponding to the 97.5% confidence level. The corresponding degrees of freedom for each test is based on the variances of the two means and was calculated using the Satterthwaite approximation, shown in Eq. 4.2.

$$\text{d.f.} = \frac{\left(\frac{s_{T2}^2}{n_{T2}} + \frac{s_{T3}^2}{n_{T3}}\right)^2}{\frac{\left(\frac{s_{T2}^2}{n_{T2}}\right)^2}{n_{T2} - 1} + \frac{\left(\frac{s_{T3}^2}{n_{T3}}\right)^2}{n_{T3} - 1}} \qquad \text{Eq. 4.2}$$

4.1 CO_2 Emissions

The CO_2 emission results of the two-sample individual vehicle tests for the FTP and HFET cycles shown in Tables 4.1.1 and 4.1.2, respectively.

For the FTP cycle (Table 4.1.1), all differences are negative, and are significant for 10 of the 11 vehicles at the 95% confidence level. The difference for the remaining vehicle, the Acura, is marginally significant. Absolute differences are generally proportional to emission levels, and range from -15 to -3 grams/mile, with an average of -6.37 grams/mile. Percent differences range from -2.3 to -1.0 %, relative to the Tier 2 level, with an average of -1.8%.

For the HFET cycle (Table 4.1.2), differences are negative for 10 of the 11 vehicles, except for the Acura, which shows a positive difference. Overall, the degree of statistical significance is not as pronounced as for the FTP. Of the 11 vehicles, six show significant differences at the 95% confidence level, including the Acura, which shows a significant positive difference. Of the remaining five vehicles, three show marginal significance ($0.05 < p < 0.10$), and two show insignificant differences ($p > 0.10$). Of the 11 vehicles, the Silverado shows the smallest and least significant difference (-0.32 g/mi, -0.1 %, p=0.75). Overall, absolute differences range from -5.14 to 1.27 g/mi, averaging -2.16 g/mi, with percent differences ranging from -2.72 to 0.74%, averaging -1.02%.

Table 4.1.1: FTP Cycle: Two-sample t-tests for differences in CO_2 emissions, by vehicle.

Vehicle	Means (g/mi)		Difference[1]		Replicates		Standard Deviations		d.f.	standard error	t_{actual}	p-value
	T2	T3	(g/mi)	(%)	n_{T2}	n_{T3}	T2	T3				
Acura	275.66	272.74	-2.92	-1.06	4	3	1.7579	1.4539	4.88	1.2154	-2.406	0.06240
Altima	276.19	270.60	-5.59	-2.02	3	5	0.9739	1.0967	4.81	0.7461	-7.486	0.00080
Malibu 1	314.53	307.37	-7.16	-2.28	3	3	0.5403	0.7474	3.64	0.5324	-13.450	0.00031
Mazda	242.12	238.57	-3.55	-1.47	3	3	1.2054	0.4800	2.62	0.7491	-4.742	0.02401
Ram	423.94	414.49	-9.46	-2.23	6	3	1.8872	3.7524	2.52	2.2993	-4.114	0.03605
Volvo	305.98	299.83	-6.15	-2.01	6	3	1.7998	0.4699	6.17	0.7832	-7.849	0.00020
Civic	216.98	213.37	-3.61	-1.66	3	3	0.8475	0.5022	3.25	0.5687	-6.340	0.00621
F150	380.61	376.87	-3.74	-0.98	3	3	1.4747	1.5390	3.99	1.2306	-3.041	0.03845
Malibu 2	274.00	268.64	-5.36	-1.96	3	5	0.4382	0.8567	5.98	0.4591	-11.676	0.00002
Silverado	427.69	419.88	-7.81	-1.83	3	6	1.5009	2.5931	6.57	1.3681	-5.707	0.00091
Silverado (2b)	721.57	706.83	-14.7	-2.04	3	3	0.5384	0.8865	3.30	0.5988	-24.616	0.00007
Means	350.84	344.47	-6.37	-1.78								

[1] Calculated as T3 - T2. and as % relative to the T2 fuel.
[2] Degrees of freedom for the difference in means. based on the Satterthwaite approximation.
[3] Two-tailed value at the 95% confidence level.

Table 4.1.2: HFET Cycle: Two-Sample *t*-tests for differences in CO_2 emissions, by vehicle.

Vehicle	Means (g/mi)		Difference[1]		Replicates		Standard Deviations		d.f.	standard error	t_{actual}	*p*-value
	T2	T3	(g/mi)	(%)	n_{T2}	n_{T3}	T2	T3				
Acura	171.31	172.58	1.27	0.74	3	3	0.3619	0.3842	3.99	0.3047	4.173	0.014
Altima	165.49	163.37	-2.13	-1.29	6	3	0.4796	1.1564	2.35	0.6958	-3.060	0.075
Malibu 1	189.15	184.01	-5.14	-2.72	3	4	2.3365	1.0493	2.61	1.4474	-3.554	0.047
Mazda	161.87	160.32	-1.54	-0.95	3	3	0.5045	0.5376	3.98	0.4256	-3.625	0.022
Ram	262.76	260.67	-2.09	-0.79	3	3	0.5913	1.2250	2.88	0.7854	-2.658	0.080
Volvo	175.61	173.22	-2.39	-1.36	3	3	0.8586	1.6970	2.96	1.0980	-2.179	0.119
Civic	144.75	143.16	-1.59	-1.10	3	3	0.3345	0.6830	2.91	0.4391	-3.627	0.038
F150	244.79	241.92	-2.87	-1.17	3	3	1.5878	0.8544	3.07	1.0410	-2.758	0.069
Malibu 2	166.02	163.58	-2.44	-1.47	3	5	0.5799	0.8100	5.59	0.4933	-4.953	0.003
Silverado	281.37	281.05	-0.32	-0.11	3	3	1.4616	0.6754	2.82	0.9296	-0.344	0.755
Silverado (2b)	447.66	443.11	-4.54	-1.02	3	3	1.7182	0.9522	3.12	1.1341	-4.007	0.026
Means	219.16	217.00	-2.16	-1.02								

[1] Calculated as T3 - T2. and as % relative to the T2 fuel.
[2] Degrees of freedom for the difference in means. based on the Satterthwaite approximation.
[3] Two-tailed value at the 95% confidence level.

4.2 Fuel Economy Results

The fuel economy results of the individual two-sample tests for fuel economy are shown in Tables 4.2.1 and 4.2.2.

For the FTP cycle (Table 4.2.1), all vehicles showed reductions in fuel economy on the Tier 3 fuel, as they did with CO_2. Absolute differences range from -1.01 to -0.24 mpg, with an average of -0.66 mpg. In relative terms, these values correspond to differences of -3.1% to -1.73%, with an average of -2.29%. All reductions are significant at the 95% confidence level for all vehicles except the Ram, which is marginally significant (p=0.054). In contrast to its behavior for CO_2, the Acura has the second largest reduction in fuel economy both in absolute and percentage terms.

For the HFET cycle (Table 4.2.2), results are similar. All vehicles show fuel economy reductions on Tier 3 fuel, ranging from -2.49 to -0.36 mpg, and averaging -1.34 mpg. Percentage differences are larger than those for the FTP on the whole, ranging from -4.8 to -0.76%, and averaging -3.0%. The Acura is distinguished in having the largest reduction, both in absolute and relative terms. For this cycle, all reductions are significant at the 95% level, except for the Malibu 1, which has the minimum absolute and relative differences (-0.36 mpg, -0.76%, p=0.47). This Malibu is also conspicuous for the size of its standard deviations, particularly on the Tier 2 fuel.

Table 4.2.1: FTP Cycle: Two-sample *t*-tests for differences in fuel economy, by vehicle.

Vehicle	Means (mpg)		Difference[1]		Replicates		Standard Deviations		d.f.	standard error	t_{actual}	*p*-value
	T2	T3	(mpg)	(%)	n_{T2}	n_{T3}	T2	T3				
Acura	32.43	31.45	-0.98	-3.02	4	3	0.2051	0.1666	4.91	0.1406	-6.972	0.00101
Altima	32.29	31.63	-0.66	-2.03	3	5	0.1017	0.1313	5.33	0.0830	-7.913	0.00038
Malibu 1	28.32	27.83	-0.49	-1.73	3	3	0.0575	0.0643	3.95	0.0498	-9.862	0.00063
Mazda	36.90	35.93	-0.97	-2.63	3	3	0.1950	0.0604	2.38	0.1179	-8.235	0.00839
Ram	21.06	20.68	-0.39	-1.83	6	3	0.0947	0.1846	2.54	0.1134	-3.399	0.05437
Volvo	29.15	28.54	-0.62	-2.12	6	3	0.1590	0.0513	6.59	0.0713	-8.665	0.00008
Civic	41.18	40.18	-1.01	-2.44	3	3	0.1635	0.0895	3.10	0.1076	-9.345	0.00227
F150	23.47	22.74	-0.73	-3.10	3	3	0.0899	0.0945	3.99	0.0753	-9.668	0.00065
Malibu 2	32.58	31.89	-0.68	-2.10	3	5	0.0434	0.1080	5.63	0.0544	-12.585	0.00002
Silverado	20.85	20.38	-0.47	-2.25	3	6	0.0740	0.1181	6.27	0.0644	-7.297	0.00028
Silverado (2b)	12.34	12.11	-0.24	-1.91	3	3	0.0109	0.0121	3.96	0.0094	-25.092	0.00002
Means	28.23	27.58	-0.66	-2.29								

[1] Calculated as T3 - T2. and as % relative to the T2 fuel.
[2] Degrees of freedom for the difference in means, based on the Satterthwaite approximation.
[3] Two-tailed value at the 95% confidence level.

Table 4.2.2: HFET Cycle: Two-sample *t*-tests for differences in fuel economy, by vehicle.

Vehicle	Means (mpg)		Difference[1]		Replicates		Standard Deviations		d.f.	standard error	t_{actual}	*p*-value
	T2	T3	(mpg)	(%)	n_{T2}	n_{T3}	T2	T3				
Acura	52.20	49.71	-2.49	-4.78	3	3	0.1109	0.1098	4.00	0.0901	-27.679	0.00001
Altima	53.88	52.42	-1.46	-2.71	6	3	0.1574	0.3655	2.38	0.2206	-6.609	0.014
Malibu 1	46.97	46.61	-0.36	-0.76	3	4	0.7011	0.2645	2.43	0.4259	-0.843	0.474
Mazda	55.22	53.49	-1.73	-3.13	3	3	0.1826	0.1743	3.99	0.1458	-11.847	0.0003
Ram	34.01	32.90	-1.11	-3.26	3	3	0.0726	0.1557	2.83	0.0992	-11.193	0.0020
Volvo	50.82	49.42	-1.41	-2.77	3	3	0.2423	0.5049	2.87	0.3233	-4.346	0.025
Civic	61.70	59.86	-1.84	-2.98	3	3	0.1493	0.2783	3.06	0.1823	-10.089	0.0019
F150	36.51	35.44	-1.07	-2.94	3	3	0.2387	0.1258	3.03	0.1558	-6.882	0.0061
Malibu 2	53.80	52.41	-1.39	-2.59	3	5	0.1982	0.2608	5.40	0.1634	-8.522	0.0002
Silverado	31.75	30.50	-1.25	-3.94	3	3	0.1659	0.0767	2.82	0.1055	-11.841	0.0017
Silverado (2b)	19.95	19.36	-0.59	-2.97	3	3	0.0757	0.0413	3.09	0.0498	-11.903	0.0011
Means	45.17	43.83	-1.34	-2.98								

[1] Calculated as T3 - T2, and as % relative to the T2 fuel.
[2] Degrees of freedom for the difference in means, based on the Satterthwaite approximation.
[3] Two-tailed value at the 95% confidence level.

4.3 Paired Tests

The absolute differences in CO_2 and fuel economy, by vehicle, are summarized graphically below. Figure 4.3.1 shows absolute changes in CO_2 emissions, by cycle. As described previously, the chart makes it clear that CO_2 reductions were larger and more significant on the FTP than on the HFET.

The reverse is true for the differences in fuel economy, shown in Figure 4.3.2. Reductions on the HFET are definitely larger for most vehicles although the degree of significance is not markedly higher.

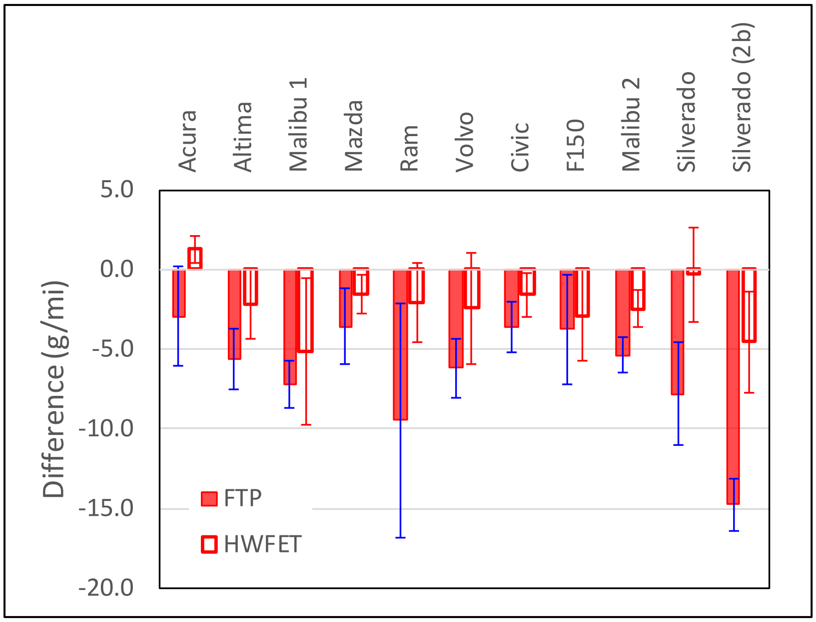

Figure 4.3.1: CO_2 Emissions: Absolute differences (g/mi), on the FTP and HFET cycles, with 95% confidence intervals (calculated as the result on T3 fuel minus that on T2 fuel).

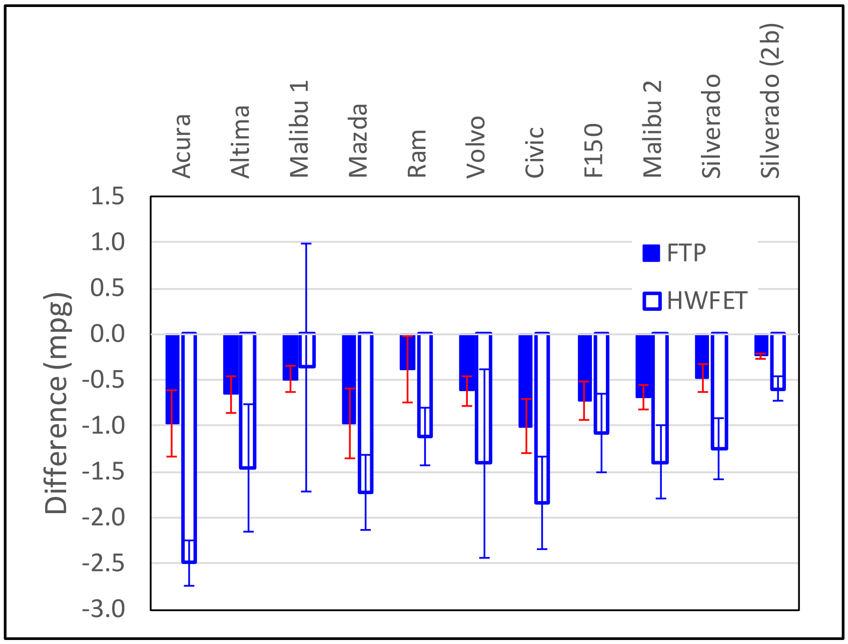

Figure 4.3.2: Fuel Economy: Absolute differences (mpg), on the FTP and HFET cycles (calculated as the result on T3 fuel minus that on T2 fuel).

The culminating step in analysis is to assess the differences in CO_2 and fuel economy for the vehicle sample as a whole. The step was achieved through the application of paired t tests to absolute emissions and fuel economy. The paired test is based on the mean and variance of the difference in means, with the difference for each vehicle calculated as shown in Eq. 4.3.1.

$$d_i = \bar{x}_{T3,i} - \bar{x}_{T2,i} \qquad \text{Eq. 4.3.1}$$

The mean difference for the vehicle sample is calculated as in Eq. 4.3.2.

$$\bar{d} = \frac{\sum_{i=1}^{n_{\text{veh}}} \left(\bar{x}_{T3,i} - \bar{x}_{T2,i} \right)}{n_{\text{veh}}} = \frac{\sum_{i=1}^{n_{\text{veh}}} d_i}{n_{\text{veh}}} \qquad \text{Eq. 4.3.2}$$

To account for the fact that the each of the vehicle means incorporated multiple replicates with their associated variability, we calculated between-vehicle and within-vehicle variance components in estimating the variance of $\bar{d}$.

The between-vehicle variance component was calculated very simply as the sum of squared errors for the d_i, with the degrees of freedom reflecting the number of vehicles in the sample (Eq. 4.3.3).

$$s_{\text{b}}^2 = \frac{\sum_{i=1}^{n_{\text{veh}}} \left(d_i - \bar{d} \right)^2}{n_{\text{veh}} - 1} \qquad \text{Eq. 4.3.3}$$

The within-vehicle variance component, analogous to an error sum of squares, was calculated by summing the pooled-sums of squares for each of the d_i, as previously shown in Eq. 4.3.4. The degrees of freedom for the within-vehicle variance component was also the sum of the degrees of freedom for individual vehicle differences.

$$s_{\text{w}}^2 = \frac{\sum_{i=1}^{n_{\text{veh}}} \left[\left(n_{T2,i} - 1 \right) s_{T2,i}^2 + \left(n_{T3,i} - 1 \right) s_{T3,i}^2 \right]}{\sum_{i=1}^{n_{\text{veh}}} \left(n_{T2,i} + n_{T3,i} - 2 \right)} \qquad \text{Eq. 4.3.4}$$

Incorporating the between-vehicle and within-vehicle variance components, the standard error of $\bar{d}$ is then calculated as shown in Eq. 4.3.5,

$$s_d = \sqrt{\frac{s_b^2}{n_{\text{veh}}} + \frac{s_w^2}{n_{\text{total}}}} \qquad \text{Eq. 4.3.5}$$

with the total of all measurements on all vehicles and fuels, denoted as n_{total}, calculated as

$$n_{\text{total}} = \sum_{i=1}^{n_{\text{veh}}} \left(n_{T2,i} + n_{T3,i} \right) \qquad \text{Eq. 4.3.6}$$

After calculating these parameters, the test statistic for the paired test, under a null hypothesis of no difference in means, is

$$t_{\text{actual}} = \frac{\bar{d} - 0}{s_d} \qquad \text{Eq. 4.3.7}$$

The critical value of t for this two-tailed test was taken at the 97.5% confidence level, with n_{veh}-1 degrees of freedom.

The results of the paired tests for CO_2 and fuel economy on both cycles are shown in Table 4.3.1. As shown above, the mean CO_2 differences for this vehicle sample are -6.4 and -2.2 grams/mile on the FTP and HFET cycles, respectively. Corresponding mean differences for fuel economy are -0.66 and -1.34 mpg. All results are highly significant. The tests for fuel economy are apparently more significant than those for CO_2 emissions. However, it is not clear that this result is of interpretive significance, given the importance of the carbon balance in the fuel economy calculation, i.e., that fuel economy is itself dependent on CO_2 emissions.

The importance of the variability of replicate measurements on the estimation of the standard error of the difference is shown in the relationships between the two variance components, each divided by their respective degrees of freedom. For CO_2, examination of the two terms in Eq. 4.3.5, prior to taking the square root, shows that the within-vehicle component accounts for 2.8% of the variance of the difference for the FTP, and 5.0% for the HFET. While the contribution of the within-vehicle component is small in both cases, it's contribution is twice as large for the HFET, reflecting the somewhat greater relative variability of replicate measurements on this cycle.

Table 4.3.1: Paired t-tests for CO_2 emissions and fuel economy, on the FTP and HFET cycles.

CO₂

Cycle	Mean Difference		n_{veh}	n_{total}	d.f.$_{\text{within}}$	s_b^2	s_w^2	s_d	t_{actual}	p-value
	(g/mi)	(%)								
FTP	-6.37	-1.78	11	80	58	11.83	2.457	1.052	-6.06	0.00012
HFET	-2.16	-1.02	11	72	50	3.11	1.090	0.546	-3.96	0.00267

Carbon-balance Fuel Economy

Cycle	Mean Difference		n_{veh}	n_{total}	d.f.$_{\text{within}}$	s_b^2	s_w^2	s_d	t_{actual}	p-value
	(mpg)	(%)								
FTP	-0.66	-2.29	11	80	58	0.0645	0.0146	0.0778	-8.45	0.000019
HFET	-1.34	-2.98	11	72	50	0.340	0.0645	0.1784	-7.49	0.000010

In the interpretation and application of these results, the ostensible transportability of the relative differences will be the most relevant factor.

Figures 4.3.3 and 4.3.4 show relative reductions in CO_2 and fuel economy on the Tier 3 fuel, relative to the Tier 2 fuel, by vehicle. Mean relative differences in CO_2 are -1.78 and -1.02% on the FTP and HFET cycles, respectively. Corresponding values for fuel economy are -2.29 and -2.98%. The charts illustrate the patterns described above, namely, that the relative differences in CO_2 are generally larger on the FTP than on the HFET (9 of 11 vehicles). The reverse holds true for fuel economy (10 of 11 vehicles).

One conclusion from this work is that the mean relative differences, at least for the FTP cycle, are in the neighborhood of the prediction from the model used to define the expected effect on CO_2 emissions in the design and conduction of the study (-1.5%). The agreement on the FTP may be due to the fact that the model was itself based on cycle aggregate emissions from the LA92 cycle, thus incorporating start and running emissions.

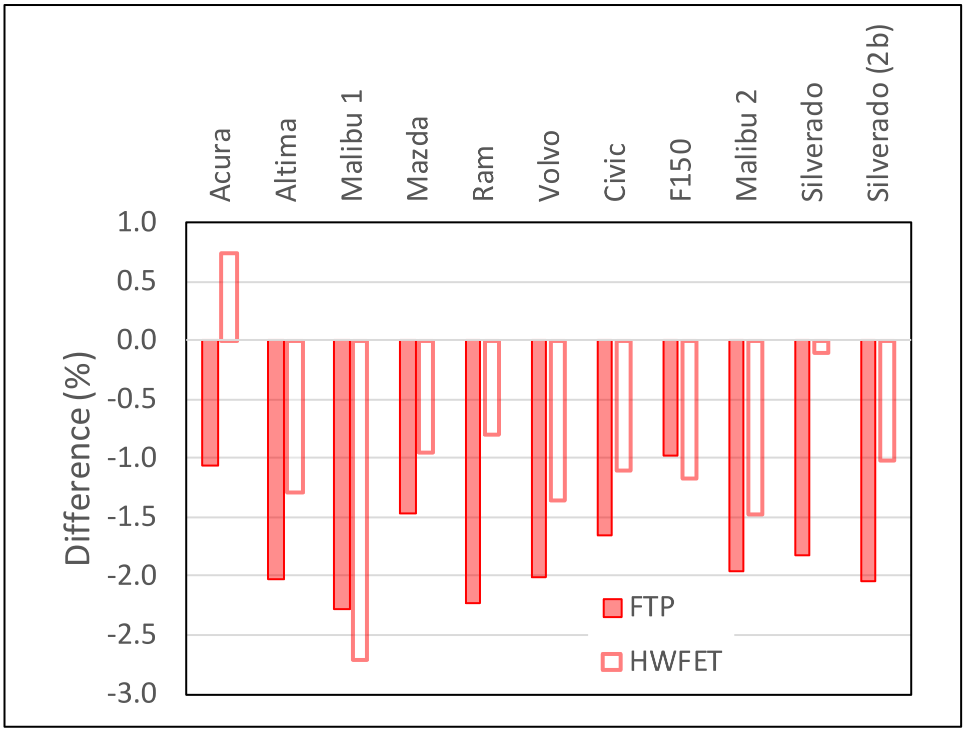

Figure 4.3.3: Relative differences in CO_2 emissions on the FTP and HFET cycles, by vehicle (calculated as 100×(T3 – T2) /T2).

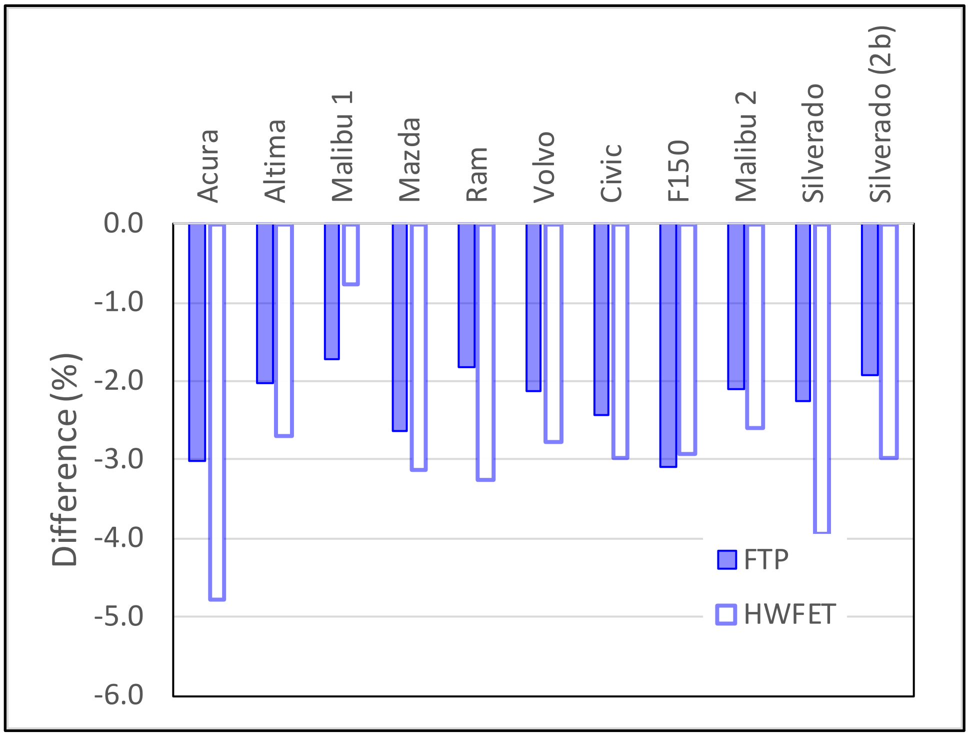

Figure 4.3.4: Relative differences in fuel economy on the FTP and HFET cycles, by vehicle (calculated as 100×(T3 – T2) /T2).

4.4 Drive Quality Statistics

After data collection the drive quality statistics were reviewed to ensure the tests were driven in a repeatable manner. All metrics were calculated according to SAE J2951, and are included in the reports generated by the dynamometer control software. Tables 4.4.1 and 4.4.2 summarize these statistics as average values by vehicle and fuel for the FTP and HFET cycles, respectively. The percentages are calculated for each metric as the driver value minus the target divided by the target, times 100 percent. These tables only include vehicles that were considered “good” tests in this analysis (see Appendix B).

Overall the results indicate the vehicles were driven consistently between the test fuels and that driver performance did not bias the CO_2 or fuel economy results. Figures 4.4.1 and 4.4.2 show the drive cycle energy metrics, where in all cases there was less than 0.5% difference in energy between test fuels on any vehicle, and roughly an equal number of vehicles where slightly more energy was used on Tier 2 fuel versus on Tier 3 fuel. There was no attempt to normalize results based on drive quality statistics within a test group or between vehicles.

The Absolute Speed Change % for HFET shows larger differences than other driver metrics especially for the Malibu 1. Since these HFETs were rerun with a different driver we would expect some differences in drive characteristics. The same driver also did the revised tests for the Altima, Acura and Silverado which also have slightly higher Absolute Speed % changes than the other vehicles. All tests fell within the required limits of the trace and for most vehicles no warnings or alarms were triggered. The Malibu 1 did have an accelerator fault code occasionally occur on the Tier 2 HFET tests with a message indicating reduced engine power, but since there was not a violation of speed trace there was not sufficient grounds to exclude the test.

Table 4.4.1: Drive quality statistics for the FTP.

Vehicle	Fuel type	Energy	Distance	Energy Economy	Absolute Speed Change	Inertial Work
Malibu 1	Tier 2	0.07%	0.00%	-0.07%	0.30%	0.30%
	Tier 3	-0.11%	0.08%	0.34%	0.13%	0.32%
Civic	Tier 2	-0.61%	-0.41%	0.21%	-0.06%	-0.28%
	Tier 3	-0.47%	-0.31%	0.16%	0.09%	0.34%
Ram	Tier 2	-0.06%	-0.09%	-0.03%	0.77%	1.19%
	Tier 3	-0.06%	-0.11%	-0.06%	0.53%	0.83%
Altima	Tier 2	1.35%	-0.34%	-1.66%	1.63%	2.15%
	Tier 3	0.94%	-0.23%	-1.16%	1.20%	1.52%
Silverado	Tier 2	-0.78%	-0.33%	0.45%	1.08%	1.72%
	Tier 3	-0.85%	-0.34%	0.51%	0.91%	1.44%
Silverado (2b)	Tier 2	-0.30%	-0.07%	0.23%	1.20%	1.73%
	Tier 3	-0.60%	-0.20%	0.41%	1.44%	2.19%
Volvo	Tier 2	-0.64%	0.00%	0.65%	0.23%	0.29%
	Tier 3	-0.72%	0.06%	0.79%	0.37%	0.52%
Acura	Tier 2	-0.15%	-0.33%	-0.18%	0.01%	-0.10%
	Tier 3	-0.48%	-0.35%	0.13%	-0.31%	-0.54%
Malibu 2	Tier 2	-0.80%	-0.01%	0.79%	0.99%	2.38%
	Tier 3	-0.89%	-0.09%	0.80%	0.84%	1.97%
Mazda	Tier 2	-1.09%	-0.02%	1.09%	-0.40%	-0.69%
	Tier 3	-1.13%	-0.14%	1.00%	-0.37%	-0.64%
F150	Tier 2	-1.36%	-0.09%	1.29%	-1.11%	-1.70%
	Tier 3	-1.22%	-0.05%	1.18%	-1.05%	-1.60%

Table 4.4.2: Drive quality statistics for the HFET.

Vehicle	Fuel type	Energy	Distance	Energy Economy	Absolute Speed Change	Inertial Work
Malibu 1	Tier 2	0.03%	-0.02%	-0.06%	9.82%	12.17%
	Tier 3	0.31%	0.09%	-0.22%	10.12%	12.75%
Civic	Tier 2	-0.70%	-0.14%	0.56%	0.69%	1.00%
	Tier 3	-0.59%	-0.12%	0.48%	0.85%	1.00%
Ram	Tier 2	0.73%	0.00%	-0.73%	4.37%	5.24%
	Tier 3	0.52%	-0.03%	-0.54%	2.56%	3.13%
Altima	Tier 2	0.62%	-0.04%	-0.65%	6.26%	8.06%
	Tier 3	0.70%	0.01%	-0.69%	5.38%	7.23%
Silverado	Tier 2	-0.59%	-0.15%	0.45%	4.88%	5.87%
	Tier 3	-0.65%	-0.20%	0.45%	4.19%	5.00%
Silverado (2b)	Tier 2	-0.69%	-0.19%	0.50%	3.86%	4.49%
	Tier 3	-0.28%	-0.14%	0.13%	3.19%	3.95%
Volvo	Tier 2	-0.80%	-0.18%	0.62%	2.61%	3.43%
	Tier 3	-0.76%	-0.14%	0.63%	2.15%	2.60%
Acura	Tier 2	0.15%	0.03%	-0.11%	2.99%	3.97%
	Tier 3	0.27%	-0.01%	-0.27%	5.70%	7.44%
Malibu 2	Tier 2	-0.76%	-0.17%	0.60%	6.13%	7.46%
	Tier 3	-0.86%	-0.14%	0.73%	6.20%	7.69%
Mazda	Tier 2	-0.63%	-0.12%	0.52%	2.45%	3.23%
	Tier 3	-0.67%	-0.19%	0.49%	2.51%	3.33%
F150	Tier 2	-0.91%	-0.17%	0.74%	-0.03%	0.13%
	Tier 3	-0.76%	-0.09%	0.66%	0.94%	1.54%

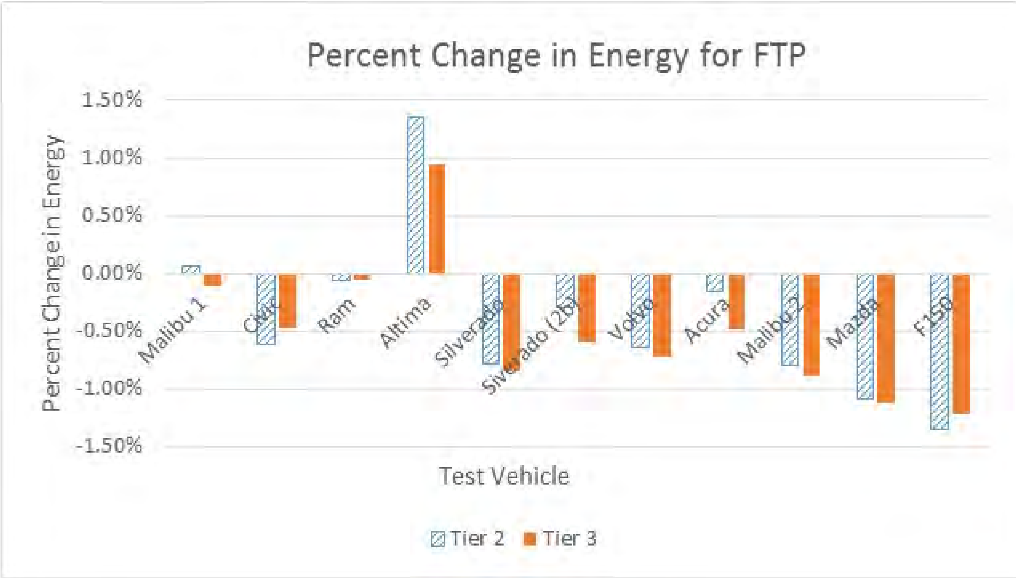

Figure 4.4.1: FTP drive cycle energy by fuel type.

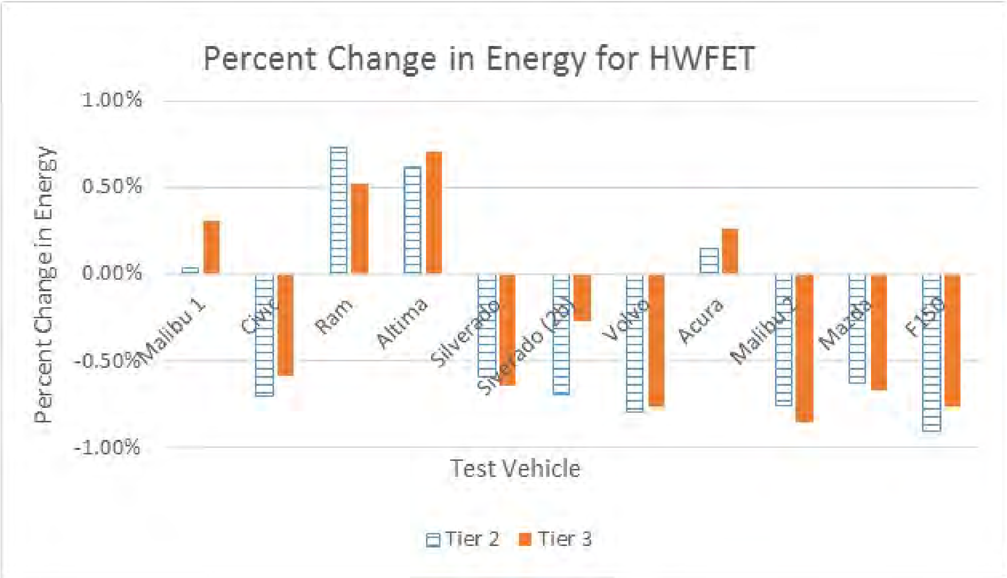

Figure 4.4.2: HFET drive cycle energy by fuel type.

4.5 Fuel-Order Effect

During the project, the Tier 2 fuel was tested as the first fuel in six vehicles, and the Tier 3 fuel tested first in the remaining five vehicles. As it was not practical to randomize the order of the test fuels for logistical reasons, we investigated the remote possibility that an order effect exists in the resulting data.

This analysis was performed by conducting paired *t*-tests for the two groups of vehicles, as described in 4.1 above. We then tested the two mean differences against each other, as shown in Eq. 4.1, as for a two-sample test, in which the standard error for the difference in the mean differences was calculated from the standard errors for each.

$$t = \frac{\bar{d}_{\mathrm{T3-1st}} - \bar{d}_{\mathrm{T2-1st}}}{\sqrt{s^2_{d,\mathrm{T3-1st}} + s^2_{d,\mathrm{T2-1st}}}} \qquad \text{Eq. 4.1}$$

The critical value for the test was taken as a two-tailed *t* statistic at the 95% confidence level with 9 degrees of freedom, estimated as 6+5-2. Results for the tests are shown in Tables 4.5.1 and 4.5.2 for results on the FTP and HFET cycles, respectively.

For the FTP cycle, the difference in the mean differences between the fuel-order groups is -1.246 g/mi. This value is roughly half of its standard error, resulting in a low *t* statistic and a highly insignificant *p*-value. The level of significance would be even lower, but for the inclusion of the 2b Silverado in the T3-first group. Its relatively large absolute difference increases the mean difference and standard error for this group, as shown graphically in Figure 4.5.1.

For the HFET cycle, the difference in the mean differences is -0.35 g/mi. This value is less than one third of its standard error, giving an insignificant p-value. This result would be even less significant if the Acura's result did not differ in sign from those for the other vehicles, thus increasing the variance for the Tier-2-first group. This is shown in Figure 4.5.2.

On the whole, the conclusion is that this analysis shows no evidence of a bias or artifact related to test fuel-order for measurements on either cycle.

Table 4.5.1. FTP Cycle: Comparison of paired *t*-tests for groups of vehicles, by fuel order.

Group	Differences		n_{veh}	s_d	*t*-statistic	*p*-value
	(g/mi)	%				
T2 first	-5.805	-1.85	6	1.008476	-5.756	0.00222
T3 first	-7.051	-1.69	5	2.184972	-3.388	0.01378
Difference	-1.246		11	2.312548	-0.538	0.6031

Table 4.5.2. HFET Cycle: Comparison of paired *t*-tests for groups of vehicles, by fuel order.

Group	Differences		n_{veh}	s_d	*t*-statistic	*p*-value
	(g/mi)	%				
T2 first	-2.004	-1.06	6	0.852321	-2.351	0.0654
T3 first	-2.354	-0.97	5	0.723467	-3.254	0.0313
Difference	-0.350		11	1.117969	-0.3131	0.7614

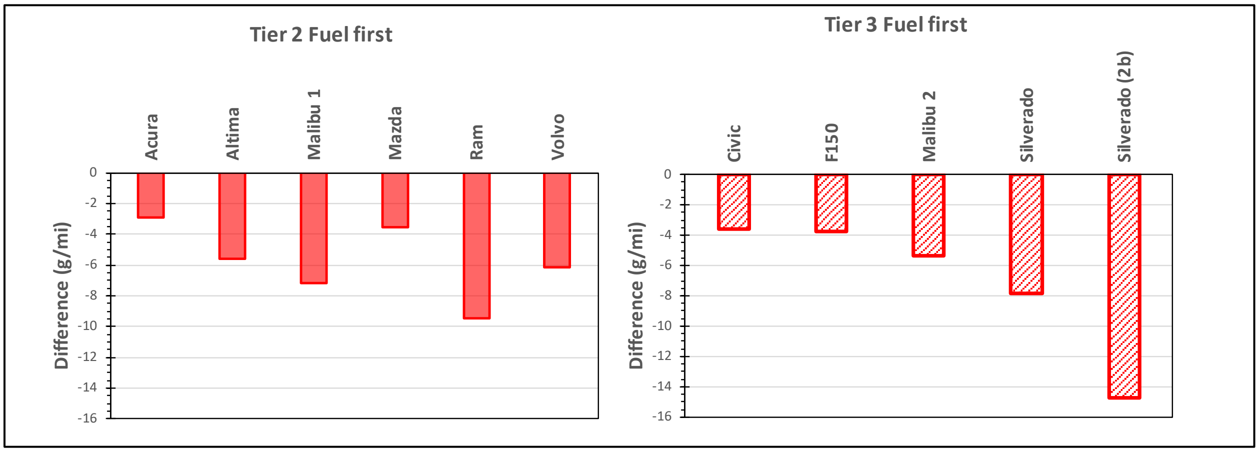

Figure 4.5.1: Absolute differences in CO_2 emissions on the FTP cycle, by test-fuel order.

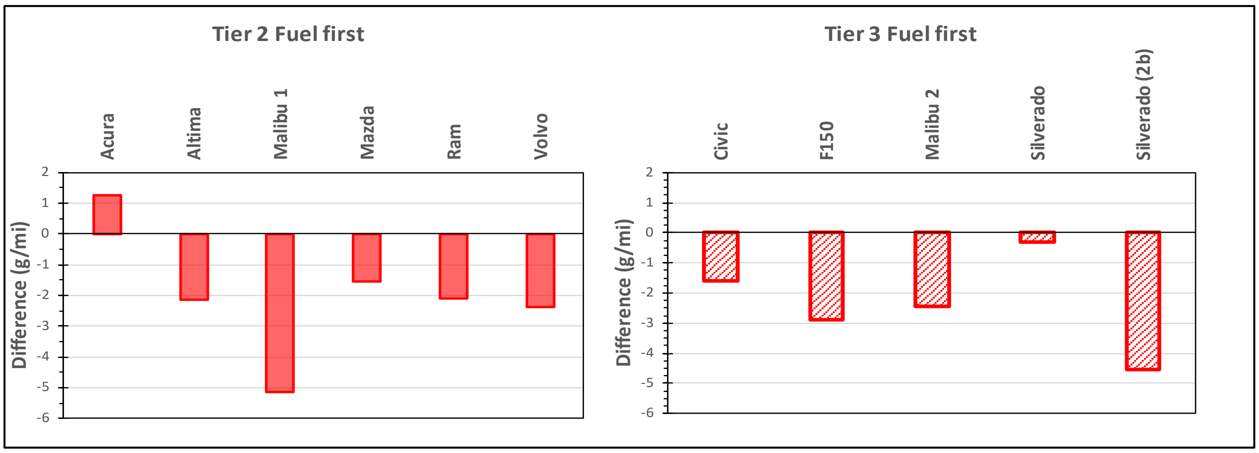

Figure 4.5.2: Absolute differences in CO_2 emissions on the HFET cycle, by test-fuel order.

5. Additional Study of Acura and Fuel Octane

During the course of testing the Acura, we encountered vehicle behavior in the HFET that was unexpected and counter to what we had observed in other vehicles, as well as being inconsistent with its own behavior over the FTP portion of the testing (see Figure 4.3.3). In an effort to better understand these observations, we performed additional testing on this vehicle using a Tier 3 premium grade test fuel to examine whether octane level could be a contributing factor.

Figure 5.1 shows CO_2 results for replicate HFET tests on the Tier 2 and Tier 3 test fuels, as well as Tier 3 premium (T3P). Note that Tier 3 regular grade and Tier 3 premium grade fuels are very closely matched in property specifications other than octane rating.[11] These results, showing equivalent performance on Tier 2 and Tier 3 premium fuels, which have very similar

[11] Tier 3 premium test fuel properties are available in Table A-5 of Appendix A.

octane but significantly different aromatics and ethanol levels, are suggestive that the vehicle is deriving a performance benefit from the additional octane value. The Tier 3 program does allow the use of higher octane fuel for any vehicle labeled as requiring premium grade fuel, however, the Acura does not have a premium fuel manufacturer recommendation and was specifically included in this study because it was not expected to be sensitive to fuel octane level.

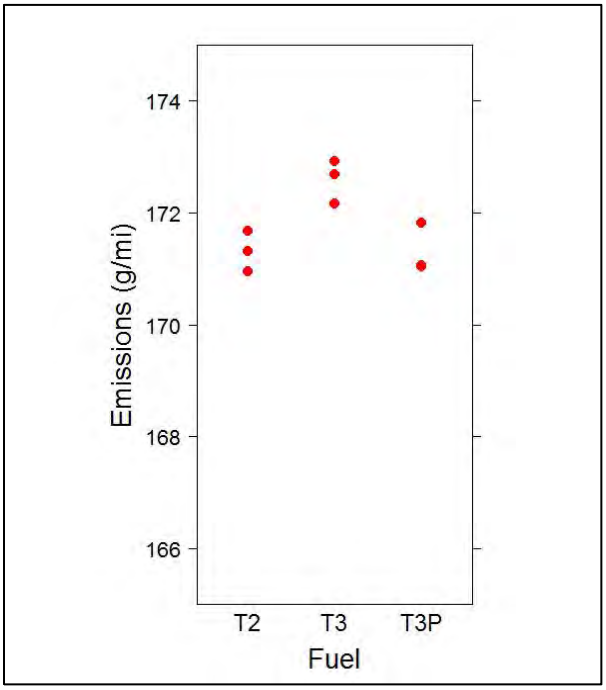

Figure 5.1: Acura CO_2 emissions over replicate HFET cycles using Tier 2, Tier 3 regular, and Tier 3 premium grade test fuels.

6. Discussion

This test program and analysis examined effects of a test fuel change on both CO_2 emission rates and fuel economy. Fuel economy is calculated from CO_2 but when comparing two fuels, these values can move in the same or opposite directions depending on fuel properties. Relative to Tier 2 test fuel, Tier 3 test fuel has less carbon per unit energy primarily due to its lower aromatic content. This difference is the primary driver for the observed lower emissions of CO_2 in grams per mile and is consistent with results of the EPAct/V2/E-89 study. At the same time, the Tier 3 fuel's lower aromatic content, as well as the presence of ethanol, lowers its volumetric energy density (Btu/gal), resulting in lower fuel economy. In other words, when using Tier 3 test fuel these results show that vehicles emit less CO_2 per mile while consuming more fuel volume than when using Tier 2 test fuel.

The test fleet consisted of eleven vehicles covering a range of advanced technologies that reasonably represent a future fleet meeting the greenhouse gas and fuel-economy standards for light- and heavy-duty applications. We observed a consistent response to the fuel change across the vehicle sample regardless of specific engine technology, lending confidence to application of these results to other engine technologies.

Fundamental to determining the small effect of this test fuel change with statistical confidence was careful study design and consistent execution of procedures from day to day. Also important was the analysis of key fuel properties at several laboratories to establish accurate inputs to the calculation of fuel economy. Additionally, driver metrics were recorded and reviewed to confirm driver behavior did not bias the fuel comparison.

The overall results across the test fleet showed a reduction in CO_2 of 1.78% for the FTP and 1.02% for the HFET tests for Tier 3 compared to Tier 2 test fuel. For fuel economy the overall reduction was 1.76% for the FTP and 2.42% for the HFET tests for Tier 3 compared to Tier 2 test fuel. Throughout, the high levels of statistical significance observed, both for CO_2 and fuel economy, suggest that the measured differences in these parameters are actual and in reasonable agreement with the difference projected during the planning of the study.

Appendix A

Supplemental Information on Test Fuels

Table A-1. Detailed data for test fuels used in this study.

Property	Test Method	Units	Tier 2 Test Fuel			Tier 3 Reg Test Fuel		
			Mean	RSD(1)	n(2)	Mean	RSD(1)	n(2)
API Gravity, 60°F	ASTM D4052	°API	58.8	0.36%	2	57.5	0.18%	2
Density, 60°F		g/cm^3	0.7430	0.10%	2	0.7482	0.06%	4
Specific Gravity, 60°F		-	0.7437	0.10%	2	0.7490	0.06%	4
DVPE (EPA equation)	ASTM D5191	psi	8.95	-	1	8.75	-	1
Ethanol	ASTM D5599	vol %	-	-	0	10.15	3.92%	3
Oxygenates other than EtOH			-	-	0	0	0.00%	3
Oxygen		mass %	-	-	0	3.74	3.81%	3
Carbon	ASTM D5291	mass %	87.01	0.40%	5	82.88	0.59%	5
Hydrogen			13.21	1.27%	5	13.59	0.89%	5
Mass% sum with oxygen	calc from D5291	mass %	100.22	0.30%	5	100.20	0.41%	5
C, normalized	calc from D5291	mass %	86.82	0.20%	5	82.70	0.19%	5
H, normalized	calc from D5291	mass %	13.18	1.32%	5	13.56	1.17%	5
Mass% sum, normalized	calc from D5291	mass %	100.00	0.00%	5	100.00	0.00%	5
Carbon Weight Fraction	calc from D5291	-	0.8682	0.20%	5	0.8270	0.19%	5
Hydrogen	ASTM D3343(3)	mass %	13.35	-	-	13.68	-	-
Carbon	calc from D3343	mass %	86.65	-	1	82.58	-	1
Sulfur	ASTM D2622	mg/kg	41.8	7.44%	2	9.2	13.14%	2
Aromatics	ASTM D1319	vol %	30.6	-	1	22.9	-	1
Olefins			0.6	-	1	5.4	-	1
Saturates			68.8	-	1	71.7	-	1
Olefins	ASTM D6550	mass %	-	-	-	6.4	-	1
Water Content	ASTM E1064	mg/kg	70	-	1	930	-	1
Existent Gum, washed	ASTM D381	mg/100ml	-	-	-	0.5	-	1
Research Octane Number	ASTM D2699	-	96.5	0.15%	2	91	-	1
Motor Octane Number	ASTM D2700	-	88.65	0.40%	2	83.5	-	1
AKI (R+M)/2	D2699/D2700	-	92.6	0.31%	2	87.25	-	1
Octane sensitivity	D2699/D2700	-	7.85	2.70%	2	7.50	-	1
Net Heat of Combustion	ASTM D3338(3)	Btu/lb	18,446	-	-	18,527	-	-
Gross Heat of Combustion, 25°C	ASTM D4809	Btu/lb	19,734	0.35%	4	19,124	0.17%	4
Gross Heat of Combustion, 25°C	ASTM D4809	MJ/kg	45.900	0.35%	4	44.482	0.17%	4
Net Heat of Combustion, 25°C	ASTM D4809	MJ/kg	43.100	0.43%	4	41.610	0.25%	4
Net Heat of Combustion, 25°C	ASTM D4809	Btu/lb	18,529	0.43%	4	17,889	0.25%	4

(1) Relative standard deviation, calculated as standard deviation divided by mean.
(2) Number of replicate fuel property measurements from different labs included in the mean.
(3) This method is a calculated result which used the mean of other property measurements, thus n and RSD were omitted.

Table A-2. Detailed data for test fuels used in this study.

Property	Test Method	Units	Tier 2 Test Fuel			Tier 3 Reg Test Fuel		
			Mean	RSD(1)	n(2)	Mean	RSD(1)	n(2)
Distillation - IBP	ASTM D86	°F	89.4	-	1	93.7	-	1
5%			111.9	-	1	120.9	-	1
10%			125.6	-	1	129.2	-	1
20%			147.0	-	1	140.5	-	1
30%			171.7	-	1	148.8	-	1
40%			201.9	-	1	154.4	-	1
50%			222.6	-	1	210.0	-	1
60%			232.4	-	1	239.9	-	1
70%			241.9	-	1	255.6	-	1
80%			259.8	-	1	286.3	-	1
90%			317.3	-	1	322.0	-	1
95%			340.7	-	1	340.2	-	1
Distillation - EP			405.9	-	1	387.0	-	1
Recovery		vol %	97.5	-	1	97.3	-	1
Residue			1.1	-	1	0.9	-	1
Loss			1.4	-	1	1.8	-	1
Benzene	ASTM D6729	vol %	0.03	-	1	0.55	-	1
Toluene			25.2	-	1	6.8	-	1
C8 Aromatics			0.9	-	1	6.4	-	1
C9 Aromatics			9.1	-	1	6.2	-	1
C10+ Aromatics			3.1	-	1	5.6	-	1
Total Aromatics			38.3	-	1	25.4	-	1
C4 Paraffins			0.7	-	1	3.5	-	1
C5 Paraffins			24.7	-	1	8.8	-	1
C6 Paraffins			6.5	-	1	8.8	-	1
C7 Paraffins			3.7	-	1	4.8	-	1
C8 Paraffins			17.7	-	1	13.4	-	1
C9 Paraffins			2.4	-	1	4.3	-	1
C10+ Paraffins			2.2	-	1	4.1	-	1
Total Paraffins			57.9	-	1	47.7	-	1
Cycloparaffins			1.0	-	1	9.7	-	1
Olefins			0.1	-	1	6.4	-	1
Ethanol			0.0	-	1	9.7	-	1
Unidentified			2.7	-	1	1.0	-	1
PM Index	See note (3)	-	1.86	-	1	1.52	-	1
Benzene	ASTM D5769	vol %	0.05	-	1	0.56	-	1
Toluene			20.0	-	1	6.2	-	1
C8 Aromatics			0.9	-	1	6.2	-	1
C9 Aromatics			9.9	-	1	5.5	-	1
C10+ Aromatics			1.5	-	1	5.4	-	1
Total Aromatics			32.3	-	1	23.8	-	1

(1) Relative standard deviation, calculated as standard deviation divided by mean.
(2) Number of replicate fuel property measurements from different labs included in the mean.
(3) Calculated as described in SAE technical paper 2010-01-2115.

Table A-3. Tier 3 regular grade emission test fuel specifications for a low-level ethanol-gasoline blend (also Table 1 of 40 CFR 1065.710).

Property	Unit	Specification			Reference procedure[1]
		General testing	Low-temp. testing	High-alt. testing	
Antiknock Index (R + M)/2	-	87.0—88.4[2]		87.0 Min.	ASTM D2699 and D2700.
Sensitivity (R-M)	-	7.5 Min.			ASTM D2699 and D2700.
Dry Vapor Pressure Equivalent (*DVPE*)[3,4]	kPa (psi)	60.0-63.4 (8.7-9.2)	77.2-81.4 (11.2-11.8)	52.4-55.2 (7.6-8.0)	ASTM D5191.
Distillation[4] 10% evaporated	°C (°F)	49-60 (120-140)	43-54 (110-130)	49-60 (120-140)	ASTM D86.
50% evaporated	°C (°F)	88-99 (190-210).			
90% evaporated	°C (°F)	157-168 (315-335).			
Evaporated final boiling point	°C (°F)	193-216 (380-420).			
Residue	ml	2.0 Max.			
Total Aromatic Hydrocarbons	vol%	21.0-25.0			ASTM D5769.
C6 Aromatics (benzene)	vol%	0.5-0.7.			
C7 Aromatics (toluene)	vol%	5.2-6.4.			
C8 Aromatics	vol%	5.2-6.4.			
C9 Aromatics	vol%	5.2-6.4.			
C10 + Aromatics	vol%	4.4-5.6.			
Olefins[5]	mass %	4.0-10.0			ASTM D6550.
Ethanol blended	vol%	9.6-10.0			See para (b)(3) of this section.
Ethanol confirmatory[6]	vol%	9.4-10.2			ASTM D4815 or D5599.
Total Content of Oxygenates Other than Ethanol[6]	vol%	0.1 Max.			ASTM D4815 or D5599.
Sulfur	mg/kg	8.0-11.0			ASTM D2622, D5453 or D7039.
Lead	g/liter	0.0026 Max.			ASTM D3237.
Phosphorus	g/liter	0.0013 Max.			ASTM D3231.
Copper Corrosion	-	No. 1 Max.			ASTM D130.
Solvent-Washed Gum Content	mg/100 milliliter	3.0 Max.			ASTM D381.
Oxidation Stability	minute	1000 Min.			ASTM D525.

[1]ASTM procedures are incorporated by reference in §1065.1010. See §1065.701(d) for other allowed procedures.

[2]Octane specifications apply to exhaust emission tests. When premium test fuel is required, as described in paragraph (d) of this section, the adjusted AKI specification is a minimum of 91.0 with no maximum. All other specifications apply for this high-octane fuel.

[3]Dry vapor pressure equivalent, *DVPE*, is intended to be equivalent to Reid Vapor Pressure using a different test method.

[4]Parenthetical values are shown for informational purposes only.

[5]The reference procedure prescribes measurement of olefin concentration in mass %. Multiply this result by 0.857 and round to the first decimal place to determine the olefin concentration in volume %.

[6]ASTM D5599 prescribes concentration measurements for ethanol and other oxygenates in mass %. Convert results to volume % as specified in Section 14.3 of ASTM D4815.

Table A-4. Tier 2 emission test fuel specifications for gasoline without ethanol (also Table 1 of 40 CFR 86.113-04).

Item	Regular	Reference procedure[1]
Research octane, Minimum[2]	93	ASTM D2699; ASTM D2700
Octane sensitivity[2]	7.5	ASTM D2699; ASTM D2700
Distillation Range (°F):		
Evaporated initial boiling point[3]	75-95	ASTM D86
10% evaporated	120-135	
50% evaporated	200-230	
90% evaporated	300-325	
Evaporated final boiling point	415 Max.	
Hydrocarbon composition (vol %):		
Olefins	10% Max.	ASTM D1319
Aromatics	35% Max.	
Saturates	Remainder	
Lead, g/gallon (g/liter), Maximum	0.050 (0.013)	ASTM D3237
Phosphorous, g/gallon (g/liter), Maximum	0.005 (0.0013)	ASTM D3231
Total sulfur, wt. %[4]	0.0015-0.008	ASTM D2622
Dry Vapor Pressure Equivalent (*DVPE*), psi (kPa)[5]	8.7-9.2 (60.0-63.4)	ASTM D5191

[1]ASTM procedures are incorporated by reference in §86.1.

[2]Octane specifications are optional for manufacturer testing.

[3]For testing at altitudes above 1,219 m (4000 feet), the specified range is 75-105 °F.

[4]Sulfur concentration will not exceed 0.0045 weight percent for EPA testing.

[5]For testing unrelated to evaporative emission control, the specified range is 8.0-9.2 psi (55.2-63.4 kPa). For testing at altitudes above 1,219 m (4000 feet), the specified range is 7.6-8.0 psi (52.4-55.2 kPa). Calculate dry vapor pressure equivalent, *DVPE,* based on the measured total vapor pressure, p_T, using the following equation: $DVPE$ (psi) = $0.956 \cdot p_T - 0.347$ (or $DVPE$ (kPa) = $0.956 \cdot p_T - 2.39$). *DVPE* is intended to be equivalent to Reid Vapor Pressure using a different test method.

Table A-5. Properties of Tier 3 premium grade emission test fuel used in this study.

Property	Test Method	Units	Tier 3 Premium Test Fuel
API Gravity, 60°F	ASTM D4052	°API	58.23
Density, 60°F		g/cm^3	0.7451
Specific Gravity, 60°F		-	0.7458
DVPE (EPA equation)	ASTM D5191	psi	8.77
Ethanol	ASTM D5599	vol %	9.80
Oxygenates other than EtOH			<0.01
Oxygen		mass %	3.62
Carbon	ASTM D5291	mass %	82.67
Hydrogen			13.70
Mass% sum with oxygen	Calc.	mass %	99.99
Aromatics	ASTM D5769	vol%	23.94
Sulfur	ASTM D5453	mg/kg	8.9
Distillation IBP	ASTM D86	°F	103.3
10%			132.6
50%			208.4
90%			325.0
Distillation EP			385.0
Olefins	ASTM D6550	vol %	5.2
Existent Gum, washed	ASTM D381	mg/100ml	0.5
Research Octane Number	ASTM D2699	-	97.8
Motor Octane Number	ASTM D2700	-	88.4
AKI (R+M)/2	ASTM D2699/D2700	-	93.1
Octane sensitivity	ASTM D2699/D2700	-	9.4
Net Heat of Combustion, 25°C	D240	Btu/lb	17,967

Appendix B

Tests Used in Analysis

Table B-1. List of tests used in CO_2 and FE analysis (page 1 of 3).

Vehicle	Test DateTime	Fuel	TestCycle	Driver	CO_2 (g/mi)	FE (mpg)	Notes
Ram	2/24/2016 11:46	Tier 2	FTP	Primary	425.07	21.04	
Ram	2/25/2016 13:02	Tier 2	FTP	Primary	423.81	21.09	
Ram	2/26/2016 8:48	Tier 2	FTP	Primary	424.77	21.07	
Ram	3/1/2016 12:30	Tier 2	FTP	Primary	420.25	21.28	
Ram	3/2/2016 10:22	Tier 2	FTP	Primary	425.35	21.04	
Ram	3/3/2016 8:22	Tier 2	FTP	Primary	424.43	21.07	
Ram	3/29/2016 10:22	Tier 3	FTP	Primary	410.44	21.03	
Ram	3/30/2016 10:04	Tier 3	FTP	Primary	417.86	20.65	
Ram	3/31/2016 7:30	Tier 3	FTP	Primary	415.15	20.79	
Ram	4/7/2016 15:02	Tier 3	HFET	Alt	261.77	32.82	
Ram	4/7/2016 15:50	Tier 3	HFET	Alt	260.90	32.93	
Ram	4/7/2016 16:38	Tier 3	HFET	Alt	259.35	33.12	
Ram	4/8/2016 14:00	Tier 2	HFET	Alt	263.13	33.83	
Ram	4/8/2016 15:02	Tier 2	HFET	Alt	263.08	33.84	
Ram	4/8/2016 15:52	Tier 2	HFET	Alt	262.08	33.96	
Silverado (2b)	6/22/2016 9:09	Tier 3	FTP	Primary	706.28	12.19	
Silverado (2b)	6/22/2016 10:21	Tier 3	HFET	Primary	442.23	19.42	
Silverado (2b)	6/23/2016 13:39	Tier 3	FTP	Primary	706.36	12.18	
Silverado (2b)	6/23/2016 14:44	Tier 3	HFET	Primary	442.99	19.39	
Silverado (2b)	6/24/2016 7:08	Tier 3	FTP	Primary	707.86	12.16	
Silverado (2b)	6/24/2016 8:24	Tier 3	HFET	Primary	444.12	19.34	
Silverado (2b)	6/28/2016 13:15	Tier 2	FTP	Primary	721.16	12.34	
Silverado (2b)	6/28/2016 14:33	Tier 2	HFET	Primary	449.34	19.79	
Silverado (2b)	6/29/2016 10:10	Tier 2	FTP	Primary	722.18	12.33	
Silverado (2b)	6/29/2016 11:21	Tier 2	HFET	Primary	447.73	19.86	
Silverado (2b)	6/30/2016 9:20	Tier 2	FTP	Primary	721.38	12.36	
Silverado (2b)	6/30/2016 10:49	Tier 2	HFET	Primary	445.90	19.94	
Acura	5/3/2016 12:22	Tier 2	FTP	Primary	276.45	32.40	
Acura	5/4/2016 7:30	Tier 2	FTP	Primary	273.92	32.68	
Acura	5/5/2016 10:45	Tier 2	FTP	Primary	277.74	32.25	
Acura	5/6/2016 7:20	Tier 2	FTP	Primary	274.54	32.61	
Acura	5/10/2016 7:19	Tier 3	FTP	Primary	271.51	31.78	
Acura	5/11/2016 13:05	Tier 3	FTP	Primary	274.34	31.48	
Acura	5/12/2016 9:07	Tier 3	FTP	Primary	272.37	31.71	
Acura	6/14/2016 14:46	Tier 3	HFET	Alt	172.16	49.91	
Acura	6/14/2016 16:03	Tier 3	HFET	Alt	172.91	49.69	
Acura	6/14/2016 16:57	Tier 3	HFET	Alt	172.68	49.76	
Acura	6/16/2016 12:53	Tier 2	HFET	Alt	171.68	51.87	
Acura	6/16/2016 14:12	Tier 2	HFET	Alt	170.95	52.09	
Acura	6/16/2016 14:57	Tier 2	HFET	Alt	171.31	51.98	
Altima	3/22/2016 9:11	Tier 2	FTP	Primary	275.07	32.40	
Altima	3/23/2016 14:39	Tier 2	FTP	Primary	276.61	32.26	
Altima	3/24/2016 8:05	Tier 2	FTP	Primary	276.88	32.27	
Altima	4/6/2016 13:06	Tier 3	FTP	Primary	270.26	31.92	
Altima	4/7/2016 7:57	Tier 3	FTP	Primary	271.23	31.78	
Altima	4/19/2016 9:10	Tier 3	FTP	Primary	269.12	32.08	
Altima	4/20/2016 12:03	Tier 3	FTP	Primary	270.37	31.94	
Altima	4/21/2016 7:28	Tier 3	FTP	Primary	272.04	31.71	
Altima	5/5/2016 15:01	Tier 2	HFET	Primary	164.62	53.95	
Altima	5/5/2016 16:34	Tier 2	HFET	Alt	165.70	53.60	
Altima	5/5/2016 17:27	Tier 2	HFET	Alt	165.53	53.67	
Altima	6/9/2016 14:55	Tier 2	HFET	Alt	165.72	53.55	
Altima	6/9/2016 16:00	Tier 2	HFET	Alt	165.38	53.65	
Altima	6/9/2016 16:48	Tier 2	HFET	Alt	166.02	53.51	
Altima	6/10/2016 15:49	Tier 3	HFET	Alt	162.05	52.92	
Altima	6/10/2016 17:09	Tier 3	HFET	Alt	163.83	52.34	
Altima	6/10/2016 17:58	Tier 3	HFET	Alt	164.22	52.24	

Table B-1. List of tests used in the CO_2 and FE analysis (page 2 of 3).

Vehicle	Test DateTime	Fuel	TestCycle	Driver	CO_2 (g/mi)	FE (mpg)	Notes
Civic	7/19/2016 7:31	Tier 3	FTP	Primary	213.20	40.40	Methane analyzer malfunction (1)
Civic	7/19/2016 10:03	Tier 3	HFET	Primary	143.90	59.65	Methane analyzer malfunction (1)
Civic	7/20/2016 12:31	Tier 3	FTP	Primary	213.94	40.28	Methane analyzer malfunction (1)
Civic	7/20/2016 13:42	Tier 3	HFET	Primary	142.56	60.19	Methane analyzer malfunction (1)
Civic	7/21/2016 9:11	Tier 3	FTP	Primary	212.97	40.45	Methane analyzer malfunction (1)
Civic	7/21/2016 10:29	Tier 3	HFET	Primary	143.00	60.00	Methane analyzer malfunction (1)
Civic	7/26/2016 13:00	Tier 2	FTP	Primary	216.86	41.14	
Civic	7/26/2016 14:13	Tier 2	HFET	Primary	145.10	61.27	
Civic	7/27/2016 7:44	Tier 2	FTP	Primary	217.88	40.96	
Civic	7/27/2016 9:00	Tier 2	HFET	Primary	144.70	61.46	
Civic	7/28/2016 9:11	Tier 2	FTP	Primary	216.19	41.28	
Civic	7/28/2016 10:25	Tier 2	HFET	Primary	144.44	61.57	
F150	7/6/2016 12:42	Tier 3	FTP	Primary	375.14	22.95	
F150	7/6/2016 13:59	Tier 3	HFET	Primary	241.00	35.63	
F150	7/7/2016 7:42	Tier 3	FTP	Primary	378.07	22.76	
F150	7/7/2016 8:57	Tier 3	HFET	Primary	242.07	35.47	
F150	7/8/2016 10:14	Tier 3	FTP	Primary	377.40	22.83	
F150	7/8/2016 11:20	Tier 3	HFET	Primary	242.69	35.38	
F150	7/12/2016 12:22	Tier 2	FTP	Primary	382.28	23.33	
F150	7/12/2016 13:39	Tier 2	HFET	Primary	246.08	36.16	
F150	7/13/2016 9:27	Tier 2	HFET	Primary	245.27	36.29	
F150	7/14/2016 13:17	Tier 2	FTP	Primary	379.49	23.52	
F150	7/14/2016 14:33	Tier 2	HFET	Primary	243.02	36.62	
F150	7/15/2016 7:39	Tier 2	FTP	Primary	380.06	23.49	
Malibu 1	3/15/2016 11:00	Tier 2	FTP	Primary	314.27	28.44	
Malibu 1	3/16/2016 10:48	Tier 2	FTP	Primary	315.15	28.39	
Malibu 1	3/17/2016 14:20	Tier 2	FTP	Primary	314.18	28.49	
Malibu 1	3/22/2016 14:57	Tier 3	FTP	Primary	308.16	28.03	
Malibu 1	3/24/2016 14:11	Tier 3	FTP	Primary	306.68	28.16	
Malibu 1	3/25/2016 8:03	Tier 3	FTP	Primary	307.28	28.08	
Malibu 1	6/6/2016 15:19	Tier 2	HFET	Alt	186.68	47.47	Accelerator fault code (2)
Malibu 1	6/6/2016 16:17	Tier 2	HFET	Alt	191.32	46.08	Accelerator fault code (2)
Malibu 1	6/6/2016 17:04	Tier 2	HFET	Alt	189.45	46.77	Accelerator fault code (2)
Malibu 1	6/15/2016 14:23	Tier 3	HFET	Alt	182.99	46.94	
Malibu 1	6/15/2016 15:35	Tier 3	HFET	Alt	184.31	46.61	
Malibu 1	6/15/2016 16:33	Tier 3	HFET	Alt	185.34	46.35	
Malibu 1	6/15/2016 17:20	Tier 3	HFET	Alt	183.39	46.84	
Malibu 2	5/17/2016 12:33	Tier 3	FTP	Primary	269.68	31.92	
Malibu 2	5/17/2016 13:43	Tier 3	HFET	Primary	163.83	52.40	
Malibu 2	5/18/2016 7:22	Tier 3	FTP	Primary	267.65	32.18	
Malibu 2	5/18/2016 8:36	Tier 3	HFET	Primary	163.38	52.53	
Malibu 2	5/19/2016 12:52	Tier 3	FTP	Primary	269.38	31.98	
Malibu 2	5/19/2016 13:57	Tier 3	HFET	Primary	163.30	52.59	
Malibu 2	5/24/2016 7:24	Tier 2	FTP	Primary	273.56	32.60	
Malibu 2	5/24/2016 9:28	Tier 2	HFET	Primary	166.60	53.39	
Malibu 2	5/25/2016 11:41	Tier 2	FTP	Primary	274.01	32.58	
Malibu 2	5/25/2016 12:55	Tier 2	HFET	Primary	166.03	53.55	
Malibu 2	5/26/2016 12:29	Tier 2	FTP	Primary	274.43	32.53	
Malibu 2	5/26/2016 14:06	Tier 2	HFET	Primary	165.44	53.78	
Malibu 2	6/14/2016 7:53	Tier 3	FTP	Primary	268.18	32.10	
Malibu 2	6/14/2016 9:03	Tier 3	HFET	Primary	164.79	52.10	
Malibu 2	6/15/2016 10:31	Tier 3	FTP	Primary	268.30	32.09	
Malibu 2	6/15/2016 11:48	Tier 3	HFET	Primary	162.59	52.81	

Table B-1. List of tests used in the CO_2 and FE analysis (page 3 of 3).

Vehicle	Test DateTime	Fuel	TestCycle	Driver	CO_2 (g/mi)	FE (mpg)	Notes
Mazda	5/17/2016 7:28	Tier 2	FTP	Primary	241.64	36.96	
Mazda	5/17/2016 9:22	Tier 2	HFET	Primary	161.62	55.07	
Mazda	5/18/2016 12:35	Tier 2	FTP	Primary	243.50	36.68	
Mazda	5/18/2016 13:53	Tier 2	HFET	Primary	161.53	55.11	
Mazda	5/19/2016 7:17	Tier 2	FTP	Primary	241.24	37.03	
Mazda	5/19/2016 10:18	Tier 2	HFET	Primary	162.45	54.78	
Mazda	5/24/2016 11:43	Tier 3	FTP	Primary	238.07	36.17	
Mazda	5/24/2016 13:09	Tier 3	HFET	Alt	160.94	53.37	
Mazda	5/25/2016 7:39	Tier 3	FTP	Primary	238.61	36.10	
Mazda	5/25/2016 8:50	Tier 3	HFET	Primary	160.06	53.66	
Mazda	5/26/2016 9:01	Tier 3	FTP	Primary	239.03	36.04	
Mazda	5/26/2016 10:31	Tier 3	HFET	Primary	159.97	53.69	
Silverado	7/6/2016 7:44	Tier 3	FTP	Primary	421.72	20.41	
Silverado	7/7/2016 13:55	Tier 3	FTP	Primary	416.27	20.62	
Silverado	7/8/2016 7:06	Tier 3	FTP	Primary	417.00	20.61	
Silverado	7/12/2016 7:16	Tier 2	FTP	Primary	427.19	20.87	
Silverado	7/13/2016 12:34	Tier 2	FTP	Primary	429.37	20.78	
Silverado	7/14/2016 9:25	Tier 2	FTP	Primary	426.49	20.90	
Silverado	7/19/2016 13:06	Tier 3	FTP	Primary	420.36	20.45	Methane analyzer malfunction (1)
Silverado	7/20/2016 7:47	Tier 3	FTP	Primary	422.12	20.38	Methane analyzer malfunction (1)
Silverado	7/21/2016 13:04	Tier 3	FTP	Primary	421.79	20.41	Methane analyzer malfunction (1)
Silverado	7/26/2016 9:18	Tier 3	HFET	Primary	281.83	30.45	
Silverado	7/26/2016 10:08	Tier 3	HFET	Primary	280.61	30.59	
Silverado	7/26/2016 11:17	Tier 3	HFET	Primary	280.71	30.58	
Silverado	7/28/2016 13:54	Tier 2	HFET	Primary	282.62	31.47	
Silverado	7/28/2016 14:45	Tier 2	HFET	Primary	279.76	31.79	
Silverado	7/28/2016 15:39	Tier 2	HFET	Primary	281.72	31.57	
Volvo	4/19/2016 13:22	Tier 2	FTP	Primary	309.08	28.90	
Volvo	4/20/2016 7:36	Tier 2	FTP	Primary	306.57	29.11	
Volvo	4/22/2016 7:30	Tier 2	FTP	Primary	304.16	29.35	
Volvo	5/3/2016 7:09	Tier 2	FTP	Primary	306.18	29.21	
Volvo	5/3/2016 9:10	Tier 2	HFET	Primary	176.36	50.39	
Volvo	5/4/2016 12:29	Tier 2	FTP	Primary	305.57	29.25	
Volvo	5/4/2016 13:54	Tier 2	HFET	Primary	175.80	50.56	
Volvo	5/5/2016 7:29	Tier 2	FTP	Primary	304.33	29.34	
Volvo	5/5/2016 8:44	Tier 2	HFET	Primary	174.67	50.87	
Volvo	5/10/2016 10:53	Tier 3	FTP	Primary	300.35	28.64	
Volvo	5/10/2016 13:37	Tier 3	HFET	Primary	173.75	49.33	
Volvo	5/11/2016 7:25	Tier 3	FTP	Primary	299.73	28.71	
Volvo	5/11/2016 8:39	Tier 3	HFET	Primary	174.59	49.08	
Volvo	5/12/2016 13:02	Tier 3	FTP	Primary	299.42	28.74	
Volvo	5/12/2016 14:08	Tier 3	HFET	Primary	171.32	50.06	

Footnotes

(1)	Malfunctioning methane analyzer could have produced a very small effect on calculated fuel economy but no effect on CO_2. Not considered sufficient grounds for excluding tests.
(2)	Accelerator fault code occasionally occurred on this vehicle, with message indicating reduced engine power. However, no violation of speed trace recorded during test. Not considered sufficient grounds for excluding tests.

Appendix C

Tests Excluded from Analysis

Table C-1. List of tests not used in the data analysis, with explanatory notes (page 1 of 2).

Vehicle	Test DateTime	Fuel	TestCycle	Driver	CO_2 (g/mi)	FE (mpg)	Notes
Ram	2/24/2016 13:51	Tier 2	HFET	Primary	266.83	33.37	PM procedural issue (1)
Ram	2/25/2016 14:21	Tier 2	HFET	Primary	267.46	33.29	PM procedural issue (1)
Ram	2/26/2016 10:47	Tier 2	HFET	Primary	268.10	33.21	PM procedural issue (1)
Ram	3/1/2016 15:20	Tier 2	HFET	Primary	268.04	33.22	PM procedural issue (1)
Ram	3/2/2016 11:48	Tier 2	HFET	Primary	267.10	33.34	PM procedural issue (1)
Ram	3/3/2016 9:48	Tier 2	HFET	Primary	266.98	33.35	PM procedural issue (1)
Ram	3/8/2016 15:36	Tier 3	FTP	Primary	411.66	20.96	Modal bench malfunction (2)
Ram	3/9/2016 11:53	Tier 3	HFET	Primary	267.35	32.13	PM procedural issue (1)
Ram	3/9/2016 13:39	Tier 3	HFET	Primary	266.32	32.26	PM procedural issue (1)
Ram	3/10/2016 14:19	Tier 3	FTP	Primary	411.28	20.98	Modal bench malfunction (2)
Ram	3/10/2016 15:41	Tier 3	HFET	Primary	262.19	32.77	PM procedural issue (1)
Ram	3/11/2016 7:26	Tier 3	FTP	Primary	414.17	20.83	Modal bench malfunction (2)
Ram	3/29/2016 11:26	Tier 3	HFET	Primary	272.27	31.55	PM procedural issue (1)
Ram	3/30/2016 11:49	Tier 3	HFET	Primary	272.07	31.58	PM procedural issue (1)
Acura	5/3/2016 13:34	Tier 2	HFET	Primary	169.66	52.49	Repeatability concerns (3)
Acura	5/4/2016 8:51	Tier 2	HFET	Primary	169.98	52.39	Repeatability concerns (3)
Acura	5/5/2016 11:55	Tier 2	HFET	Primary	172.50	51.62	Repeatability concerns (3)
Acura	5/6/2016 8:45	Tier 2	HFET	Primary	171.97	51.78	Repeatability concerns (3)
Acura	5/10/2016 8:48	Tier 3	HFET	Primary	171.86	50.00	Repeatability concerns (3)
Acura	5/11/2016 14:25	Tier 3	HFET	Primary	171.95	49.97	Repeatability concerns (3)
Acura	5/12/2016 10:30	Tier 3	HFET	Primary	171.33	50.15	Repeatability concerns (3)
Altima	3/22/2016 11:22	Tier 2	HFET	Primary	170.85	51.94	PM procedural issue (1)
Altima	3/24/2016 9:24	Tier 2	HFET	Primary	172.05	51.64	PM procedural issue (1)
Altima	3/24/2016 10:17	Tier 2	HFET	Primary	170.65	52.06	PM procedural issue (1)
Altima	4/5/2016 8:45	Tier 3	FTP	Primary	278.87	30.91	Irregular test/prep sequence (4)
Altima	4/5/2016 10:50	Tier 3	HFET	Primary	174.27	49.19	PM procedural issue (1)
Altima	4/6/2016 14:14	Tier 3	HFET	Primary	166.23	51.60	PM procedural issue (1)
Altima	4/7/2016 9:10	Tier 3	HFET	Primary	170.60	50.26	PM procedural issue (1)
Altima	4/19/2016 10:27	Tier 3	HFET	Primary	168.92	50.77	PM procedural issue (1)
Altima	4/20/2016 13:53	Tier 3	HFET	Primary	171.54	50.00	PM procedural issue (1)
Altima	4/21/2016 10:53	Tier 3	HFET	Primary	167.46	51.19	PM procedural issue (1)
Altima	4/29/2016 14:52	Tier 3	HFET	Alt	169.28	50.62	Repeatability concerns (5)
Altima	4/29/2016 15:49	Tier 3	HFET	Alt	166.88	51.35	Repeatability concerns (5)
Altima	4/29/2016 16:35	Tier 3	HFET	Alt	167.45	51.20	Repeatability concerns (5)
Altima	6/7/2016 15:35	Tier 2	HFET	Alt	169.75	52.24	Repeatability concerns (5)
Altima	6/7/2016 16:47	Tier 2	HFET	Alt	167.90	52.90	Repeatability concerns (5)
Altima	6/7/2016 17:38	Tier 2	HFET	Alt	165.97	53.48	Repeatability concerns (5)
Malibu 1	3/8/2016 10:17	Tier 2	FTP	Primary	314.12	28.46	Irregular test/prep sequence (4)
Malibu 1	3/8/2016 11:31	Tier 2	HFET	Primary	190.44	46.64	PM procedural issue (1)
Malibu 1	3/9/2016 16:14	Tier 2	FTP	Primary	319.21	27.95	Modal bench malfunction (2)
Malibu 1	3/10/2016 7:55	Tier 2	FTP	Primary	318.15	28.05	Modal bench malfunction (2)
Malibu 1	3/10/2016 9:20	Tier 2	HFET	Primary	191.49	46.40	PM procedural issue (1)
Malibu 1	3/10/2016 10:33	Tier 2	HFET	Primary	191.89	46.29	PM procedural issue (1)
Malibu 1	3/15/2016 13:35	Tier 2	HFET	Primary	190.50	46.64	PM procedural issue (1)
Malibu 1	3/16/2016 12:59	Tier 2	HFET	Primary	189.99	46.76	PM procedural issue (1)
Malibu 1	3/17/2016 15:31	Tier 2	HFET	Primary	189.60	46.86	PM procedural issue (1)
Malibu 1	3/23/2016 8:15	Tier 3	FTP	Primary	311.80	27.64	Irregular test/prep sequence (4)
Malibu 1	3/23/2016 10:14	Tier 3	HFET	Primary	187.43	45.78	PM procedural issue (1)
Malibu 1	3/23/2016 11:09	Tier 3	HFET	Primary	187.15	45.85	PM procedural issue (1)
Malibu 1	3/25/2016 9:57	Tier 3	HFET	Primary	186.67	45.97	PM procedural issue (1)
Malibu 1	5/20/2016 9:39	Tier 3	HFET	Alt	204.28	41.96	Repeatability concerns (6)
Malibu 1	5/20/2016 10:58	Tier 3	HFET	Alt	204.30	41.87	Repeatability concerns (6)
Malibu 1	5/20/2016 11:53	Tier 3	HFET	Alt	203.03	42.20	Repeatability concerns (6)
Malibu 1	6/2/2016 15:30	Tier 2	HFET	Alt	203.70	43.68	Repeatability concerns (6)
Malibu 1	6/2/2016 16:59	Tier 2	HFET	Alt	209.40	42.47	Repeatability concerns (6)
Malibu 1	6/2/2016 17:59	Tier 2	HFET	Alt	206.86	43.00	Repeatability concerns (6)

Table C-1. List of tests not used in the data analysis, with explanatory notes (page 2 of 2).

Vehicle	Test DateTime	Fuel	TestCycle	Driver	CO_2 (g/mi)	FE (mpg)	Notes
Silverado	7/6/2016 9:40	Tier 3	HFET	Primary	280.42	30.59	Repeatability concerns (7)
Silverado	7/7/2016 14:57	Tier 3	HFET	Primary	275.07	31.22	Repeatability concerns (7)
Silverado	7/8/2016 8:18	Tier 3	HFET	Primary	281.84	30.44	Repeatability concerns (7)
Silverado	7/12/2016 8:54	Tier 2	HFET	Primary	279.16	31.88	Repeatability concerns (7)
Silverado	7/13/2016 13:36	Tier 2	HFET	Primary	280.46	31.72	Repeatability concerns (7)
Silverado	7/14/2016 10:44	Tier 2	HFET	Primary	279.21	31.86	Repeatability concerns (7)
Silverado	7/19/2016 14:27	Tier 3	HFET	Primary	282.72	30.33	Repeatability concerns (7)
Silverado	7/20/2016 9:00	Tier 3	HFET	Primary	279.82	30.67	Repeatability concerns (7)
Silverado	7/21/2016 14:06	Tier 3	HFET	Primary	278.28	30.84	Repeatability concerns (7)
Volvo	4/5/2016 15:46	Tier 2	HFET	Primary	184.30	48.19	PM procedural issue (1)
Volvo	4/6/2016 7:25	Tier 2	FTP	Primary	310.07	28.79	Irregular test/prep sequence (4)
Volvo	4/6/2016 8:36	Tier 2	HFET	Primary	183.60	48.40	PM procedural issue (1)
Volvo	4/7/2016 12:01	Tier 2	FTP	Primary	325.34	27.62	Irregular test/prep sequence (4)
Volvo	4/7/2016 13:04	Tier 2	HFET	Primary	181.72	48.89	PM procedural issue (1)
Volvo	4/19/2016 14:30	Tier 2	HFET	Primary	184.15	48.23	PM procedural issue (1)
Volvo	4/20/2016 8:49	Tier 2	HFET	Primary	183.00	48.55	PM procedural issue (1)
Volvo	4/22/2016 8:57	Tier 2	HFET	Primary	180.53	49.22	PM procedural issue (1)

Footnotes

(1)	PM filter holders for unused test phases were configured inconsistently in this test, producing an unknown error in all gaseous results and thus we excluded this test.
(2)	A malfunction in the modal bench caused an error in calculated results for gaseous bag emissions, which was sufficient ground for excluding this test.
(3)	Initial HFET results for the Acura showed no clear effect of test fuel, which was inconsistent with FTP results. We added a controlled experiment with additional replicates comparing the fuels, and the result suggested an opposite fuel effect. This latter experiment used a different driver, and we did not want to mix data from different drivers so we used the newer data in the overall analysis. Additional tests with Tier 3 premium fuel indicated an effect of octane on CO_2 emissions, which could explain the opposite fuel effect observed with Tier 3 regular. The tests performed on T3 premium were not included in the overall analysis.
(4)	We observed higher emission variability when prior day's test sequence was inconsistent with the test plan. We also generally attempted to keep testing in 4-day work-week blocks.
(5)	Initial HFET tests for the Altima were repeated in a later experiment because of the filter holder issue (1). In this later experiment, the intial fuel effect was inconsistent with FTP results so a decision was made to conduct additional confirmatory tests. These results showed a large spread with descending CO_2 results, and it was determined that the trickle charger had not been connected during several weeks of vehicle storage prior to these additional tests. After ensuring the vehicle battery was charged, another test set was performed. This final set was retained in the dataset.
(6)	Initial HFET tests for the Malibu 1were repeated in a later experiment die to the filter holder issue (1). The initial fuel comparison in this experiment showed a trend inconsistent with the FTP data. At this point we had concerns about repeatability after vehicle had been used by another testing group and returned to us with a fault code. Actions were taken to resolve any issues, and an additional test set was performed over the following two weeks. This final set was retained in the dataset.
(7)	Initial HFET results for the Silverado showed no clear effect of test fuel, which was inconsistent with FTP results. We added a controlled experiment with additional replicates comparing the fuels, which confirmed the original result of no effect. This later experiment used a different driver, and we did not want to mix data from different drivers so we used the newer data in the overall analysis.

Appendix D

Supplemental Emissions Data

Table D1. Supplemental emissions data for tests included in the analyses (page 1 of 3).[a]

Vehicle	Fuel	TestCycle	Test Date/Time	THC (g/mi)	CH_4 (g/mi)	CO (g/mi)	NMOG (g/mi)	NOx (g/mi)	PM (mg/mi)
Silverado (2b)	Tier 2	FTP	6/28/2016 13:15	0.1530	0.0286	1.8638	0.1295	0.0201	1.4843
Silverado (2b)	Tier 2	FTP	6/29/2016 10:10	0.0662	0.0248	1.7805	0.0450	0.0193	0.9988
Silverado (2b)	Tier 2	FTP	6/30/2016 9:20	0.0613	0.0225	1.4870	0.0417	0.0197	0.7846
Silverado (2b)	Tier 2	HFET	6/28/2016 14:33	0.0177	0.0133	0.3551	0.0054	0.0082	1.0188
Silverado (2b)	Tier 2	HFET	6/29/2016 11:21	0.0171	0.0132	0.3897	0.0049	0.0090	0.9497
Silverado (2b)	Tier 2	HFET	6/30/2016 10:49	0.0167	0.0128	0.3799	0.0048	0.0096	0.8718
Silverado (2b)	Tier 3	FTP	6/22/2016 9:09	0.0499	0.0165	1.0437	0.0386	0.0199	1.2380
Silverado (2b)	Tier 3	FTP	6/23/2016 13:39	0.0506	0.0174	1.2281	0.0391	0.0180	
Silverado (2b)	Tier 3	FTP	6/24/2016 7:08	0.0486	0.0168	0.9187	0.0365	0.0213	
Silverado (2b)	Tier 3	HFET	6/22/2016 10:21	0.0068	0.0067	0.0701	0.0005	0.0033	1.1232
Silverado (2b)	Tier 3	HFET	6/23/2016 14:44	0.0057	0.0062	0.0714	0.0000	0.0041	
Silverado (2b)	Tier 3	HFET	6/24/2016 8:24	0.0062	0.0064	0.0632	0.0002	0.0037	
Acura	Tier 2	FTP	5/3/2016 12:22	0.0147	0.0031	0.0465	0.0124	0.0180	
Acura	Tier 2	FTP	5/4/2016 7:30	0.0228	0.0032	0.0558	0.0205	0.0200	0.1200
Acura	Tier 2	FTP	5/5/2016 10:45	0.0122	0.0031	0.0532	0.0099	0.0177	
Acura	Tier 2	FTP	5/6/2016 7:20	0.0131	0.0028	0.0478	0.0108	0.0173	0.2067
Acura	Tier 2	HFET	6/16/2016 12:53	0.0004	0.0006	0.0026	0.0000	0.0052	
Acura	Tier 2	HFET	6/16/2016 14:12	0.0004	0.0006	0.0002	0.0000	0.0034	
Acura	Tier 2	HFET	6/16/2016 14:57	0.0003	0.0006	0.0004	0.0000	0.0042	
Acura	Tier 3	FTP	5/10/2016 7:19	0.0162	0.0034	0.0256	0.0146	0.0237	
Acura	Tier 3	FTP	5/11/2016 13:05	0.0121	0.0034	0.0249	0.0103	0.0215	0.2723
Acura	Tier 3	FTP	5/12/2016 9:07	0.0115	0.0030	0.0258	0.0099	0.0199	
Acura	Tier 3	HFET	6/14/2016 14:46	0.0004	0.0005	0.0059	0.0000	0.0045	
Acura	Tier 3	HFET	6/14/2016 16:03	0.0004	0.0005	0.0015	0.0000	0.0034	
Acura	Tier 3	HFET	6/14/2016 16:57	0.0004	0.0005	0.0030	0.0000	0.0033	
Altima	Tier 2	FTP	3/22/2016 9:11	0.0239	0.0068	0.5167	0.0183	0.0124	0.5970
Altima	Tier 2	FTP	3/23/2016 14:39	0.0112	0.0059	0.4765	0.0063	0.0104	0.6672
Altima	Tier 2	FTP	3/24/2016 8:05	0.0158	0.0059	0.3861	0.0109	0.0108	0.5325
Altima	Tier 2	HFET	5/5/2016 15:01	0.0030	0.0022	0.2792	0.0010	0.0020	
Altima	Tier 2	HFET	5/5/2016 16:34	0.0036	0.0039	0.2818	0.0000	0.0036	
Altima	Tier 2	HFET	5/5/2016 17:27	0.0048	0.0048	0.2411	0.0004	0.0051	
Altima	Tier 2	HFET	6/9/2016 14:55	0.0034	0.0035	0.3644	0.0001	0.0032	
Altima	Tier 2	HFET	6/9/2016 16:00	0.0042	0.0045	0.3814	0.0000	0.0036	
Altima	Tier 2	HFET	6/9/2016 16:48	0.0030	0.0035	0.2463	0.0000	0.0032	
Altima	Tier 3	FTP	4/6/2016 13:06	0.0100	0.0051	0.3258	0.0063	0.0088	0.3376
Altima	Tier 3	FTP	4/7/2016 7:57	0.0145	0.0050	0.4100	0.0113	0.0095	0.2591
Altima	Tier 3	FTP	4/19/2016 9:10	0.0127	0.0053	0.3849	0.0089	0.0097	0.4698
Altima	Tier 3	FTP	4/20/2016 12:03	0.0096	0.0051	0.3294	0.0059	0.0088	0.2306
Altima	Tier 3	FTP	4/21/2016 7:28	0.0122	0.0053	0.4017	0.0083	0.0128	0.3164
Altima	Tier 3	HFET	6/10/2016 15:49	0.0011	0.0015	0.1977	0.0000	0.0017	
Altima	Tier 3	HFET	6/10/2016 17:09	0.0014	0.0018	0.2020	0.0000	0.0023	
Altima	Tier 3	HFET	6/10/2016 17:58	0.0015	0.0019	0.1601	0.0000	0.0033	
Civic	Tier 2	FTP	7/26/2016 13:00	0.0162	0.0080	0.0899	0.0090	0.0121	0.7907
Civic	Tier 2	FTP	7/27/2016 7:44	0.0196	0.0078	0.0924	0.0127	0.0133	0.5581
Civic	Tier 2	FTP	7/28/2016 9:11	0.0148	0.0078	0.0822	0.0079	0.0116	0.6652
Civic	Tier 2	HFET	7/26/2016 14:13	0.0006	0.0011	0.1466	0.0000	0.0008	0.1530
Civic	Tier 2	HFET	7/27/2016 9:00	0.0006	0.0010	0.1200	0.0000	0.0008	0.1688
Civic	Tier 2	HFET	7/28/2016 10:25	0.0009	0.0012	0.1279	0.0000	0.0009	0.1988
Civic	Tier 3	FTP	7/19/2016 7:31	0.0195	0.0078	0.0684	0.0215	0.0116	0.4757
Civic	Tier 3	FTP	7/20/2016 12:31	0.0158	0.0078	0.0473	0.0174	0.0123	0.6495
Civic	Tier 3	FTP	7/21/2016 9:11	0.0159	0.0078	0.0770	0.0175	0.0130	0.5276
Civic	Tier 3	HFET	7/19/2016 10:03	0.0007	0.0011	0.0994	0.0007	0.0008	0.0977
Civic	Tier 3	HFET	7/20/2016 13:42	0.0008	0.0011	0.1159	0.0008	0.0012	0.0504
Civic	Tier 3	HFET	7/21/2016 10:29	0.0008	0.0011	0.1242	0.0009	0.0008	

Table D1. Supplemental emissions data for tests included in the analyses (page 2 of 3).

Vehicle	Fuel	TestCycle	Test Date/Time	THC (g/mi)	CH_4 (g/mi)	CO (g/mi)	NMOG (g/mi)	NOx (g/mi)	PM (mg/mi)
F150	Tier 2	FTP	7/12/2016 12:22	0.0322	0.0103	0.2214	0.0233	0.0083	2.8749
F150	Tier 2	FTP	7/14/2016 13:17	0.0300	0.0000	0.2446	0.0308	0.0085	3.6695
F150	Tier 2	FTP	7/15/2016 7:39	0.0385	0.0137	0.2104	0.0285	0.0113	3.4875
F150	Tier 2	HFET	7/12/2016 13:39	0.0004	0.0009	0.1087	0.0000	0.0017	0.2706
F150	Tier 2	HFET	7/13/2016 9:27	0.0008	0.0014	0.0934	0.0000	0.0020	0.2200
F150	Tier 2	HFET	7/14/2016 14:33	0.0007	0.0000	0.0947	0.0007	0.0017	0.2579
F150	Tier 3	FTP	7/6/2016 12:42	0.0401	0.0100	0.1730	0.0340	0.0080	4.4866
F150	Tier 3	FTP	7/7/2016 7:42	0.0424	0.0123	0.2210	0.0344	0.0096	3.8411
F150	Tier 3	FTP	7/8/2016 10:14	0.0322	0.0106	0.1635	0.0250	0.0081	4.0318
F150	Tier 3	HFET	7/6/2016 13:59	0.0008	0.0011	0.1046	0.0000	0.0016	0.2800
F150	Tier 3	HFET	7/7/2016 8:57	0.0008	0.0012	0.1052	0.0000	0.0017	0.3505
F150	Tier 3	HFET	7/8/2016 11:20	0.0007	0.0011	0.1101	0.0000	0.0016	0.3465
Malibu 1	Tier 2	FTP	3/15/2016 11:00	0.0234	0.0070	0.7375	0.0176	0.0117	2.8690
Malibu 1	Tier 2	FTP	3/16/2016 10:48	0.0222	0.0084	0.8118	0.0151	0.0120	2.3943
Malibu 1	Tier 2	FTP	3/17/2016 14:20	0.0177	0.0073	0.6824	0.0118	0.0111	2.2597
Malibu 1	Tier 2	HFET	6/6/2016 15:19	0.0173	0.0106	0.5395	0.0077	0.0035	
Malibu 1	Tier 2	HFET	6/6/2016 16:17	0.0299	0.0151	1.1752	0.0162	0.0021	
Malibu 1	Tier 2	HFET	6/6/2016 17:04	0.0163	0.0104	0.5764	0.0068	0.0013	
Malibu 1	Tier 3	FTP	3/22/2016 14:57	0.0149	0.0059	0.4838	0.0110	0.0118	3.0627
Malibu 1	Tier 3	FTP	3/24/2016 14:11	0.0159	0.0070	0.5214	0.0110	0.0107	2.8856
Malibu 1	Tier 3	FTP	3/25/2016 8:03	0.0200	0.0068	0.6101	0.0156	0.0116	3.0935
Malibu 1	Tier 3	HFET	6/15/2016 14:23	0.0003	0.0008	0.0347	0.0000	0.0037	
Malibu 1	Tier 3	HFET	6/15/2016 15:35	0.0007	0.0011	0.0272	0.0000	0.0044	
Malibu 1	Tier 3	HFET	6/15/2016 16:33	0.0018	0.0021	0.0304	0.0000	0.0049	
Malibu 1	Tier 3	HFET	6/15/2016 17:20	0.0026	0.0029	0.0328	0.0000	0.0049	
Malibu 2	Tier 2	FTP	5/24/2016 7:24	0.0170	0.0047	0.3724	0.0130	0.0094	2.5376
Malibu 2	Tier 2	FTP	5/25/2016 11:41	0.0077	0.0030	0.2475	0.0053	0.0024	2.7309
Malibu 2	Tier 2	FTP	5/26/2016 12:29	0.0082	0.0032	0.2891	0.0057	0.0041	2.7257
Malibu 2	Tier 2	HFET	5/24/2016 9:28	0.0001	0.0005	0.1313	0.0000	0.0011	1.5311
Malibu 2	Tier 2	HFET	5/25/2016 12:55	0.0000	0.0002	0.1653	0.0000	0.0015	1.5110
Malibu 2	Tier 2	HFET	5/26/2016 14:06	0.0000	0.0001	0.0945	0.0000	0.0025	1.3014
Malibu 2	Tier 3	FTP	5/17/2016 12:33	0.0135	0.0044	0.2926	0.0103	0.0024	2.6620
Malibu 2	Tier 3	FTP	5/18/2016 7:22	0.0146	0.0037	0.2114	0.0125	0.0027	2.8018
Malibu 2	Tier 3	FTP	5/19/2016 12:52	0.0080	0.0030	0.2107	0.0058	0.0071	2.5406
Malibu 2	Tier 3	FTP	6/14/2016 7:53	0.0078	0.0032	0.1726	0.0054	0.0024	2.5665
Malibu 2	Tier 3	FTP	6/15/2016 10:31	0.0068	0.0025	0.1693	0.0051	0.0080	2.5896
Malibu 2	Tier 3	HFET	5/17/2016 13:43	0.0004	0.0001	0.0864	0.0003	0.0018	2.8146
Malibu 2	Tier 3	HFET	5/18/2016 8:36	0.0002	0.0002	0.1125	0.0001	0.0012	1.7568
Malibu 2	Tier 3	HFET	5/19/2016 13:57	0.0000	0.0001	0.0595	0.0000	0.0028	1.6465
Malibu 2	Tier 3	HFET	6/14/2016 9:03	0.0000	0.0001	0.0791	0.0000	0.0033	1.5561
Malibu 2	Tier 3	HFET	6/15/2016 11:48	0.0000	0.0000	0.0689	0.0000	0.0014	1.4652
Mazda	Tier 2	FTP	5/17/2016 7:28	0.0169	0.0045	0.0874	0.0131	0.0067	1.2025
Mazda	Tier 2	FTP	5/18/2016 12:35	0.0159	0.0053	0.1752	0.0112	0.0054	1.3648
Mazda	Tier 2	FTP	5/19/2016 7:17	0.0131	0.0039	0.0916	0.0097	0.0065	1.1983
Mazda	Tier 2	HFET	5/17/2016 9:22	0.0034	0.0025	0.0387	0.0010	0.0019	0.0337
Mazda	Tier 2	HFET	5/18/2016 13:53	0.0059	0.0032	0.0336	0.0030	0.0015	0.0129
Mazda	Tier 2	HFET	5/19/2016 10:18	0.0078	0.0041	0.0650	0.0041	0.0018	0.0739
Mazda	Tier 3	FTP	5/24/2016 11:43	0.0160	0.0054	0.1642	0.0121	0.0054	2.1290
Mazda	Tier 3	FTP	5/25/2016 7:39	0.0115	0.0040	0.0770	0.0085	0.0067	1.8756
Mazda	Tier 3	FTP	5/26/2016 9:01	0.0114	0.0042	0.0756	0.0084	0.0066	2.0560
Mazda	Tier 3	HFET	5/24/2016 13:09	0.0008	0.0008	0.0272	0.0000	0.0022	0.0739
Mazda	Tier 3	HFET	5/25/2016 8:50	0.0006	0.0007	0.0522	0.0000	0.0018	0.0575
Mazda	Tier 3	HFET	5/26/2016 10:31	0.0005	0.0006	0.0368	0.0000	0.0022	0.0394

Table D1. Supplemental emissions data for tests included in the analyses (page 3 of 3).

Vehicle	Fuel	TestCycle	Test Date/Time	THC (g/mi)	CH_4 (g/mi)	CO (g/mi)	NMOG (g/mi)	NOx (g/mi)	PM (mg/mi)
Ram	Tier 2	FTP	2/24/2016 11:46	0.0178	0.0037	0.3175	0.0151	0.0081	0.1850
Ram	Tier 2	FTP	2/25/2016 13:02	0.0824	0.0060	0.4532	0.0787	0.0111	0.6961
Ram	Tier 2	FTP	2/26/2016 8:48	0.0188	0.0040	0.3852	0.0157	0.0073	0.1127
Ram	Tier 2	FTP	3/1/2016 12:30	0.0160	0.0033	0.3021	0.0135	0.0062	0.1441
Ram	Tier 2	FTP	3/2/2016 10:22	0.0183	0.0022	0.2619	0.0169	0.0107	0.1223
Ram	Tier 2	FTP	3/3/2016 8:22	0.0181	0.0031	0.2881	0.0157	0.0058	0.0734
Ram	Tier 2	HFET	4/8/2016 14:00	0.0000	0.0004	0.0639	0.0000	0.0059	
Ram	Tier 2	HFET	4/8/2016 15:02	0.0000	0.0003	0.0639	0.0000	0.0072	
Ram	Tier 2	HFET	4/8/2016 15:52	0.0000	0.0005	0.0909	0.0000	0.0044	
Ram	Tier 3	FTP	3/29/2016 10:22	0.0143	0.0031	0.2769	0.0129	0.0073	0.0674
Ram	Tier 3	FTP	3/30/2016 10:04	0.0148	0.0032	0.2051	0.0132	0.0077	0.1006
Ram	Tier 3	FTP	3/31/2016 7:30	0.0178	0.0032	0.2153	0.0164	0.0091	0.0585
Ram	Tier 3	HFET	4/7/2016 15:02	0.0000	0.0001	0.0400	0.0000	0.0036	
Ram	Tier 3	HFET	4/7/2016 15:50	0.0000	0.0002	0.0317	0.0000	0.0030	
Ram	Tier 3	HFET	4/7/2016 16:38	0.0000	0.0002	0.0307	0.0000	0.0047	
Silverado	Tier 2	FTP	7/12/2016 7:16	0.0436	0.0120	0.7421	0.0335	0.0042	1.3943
Silverado	Tier 2	FTP	7/13/2016 12:34	0.0382	0.0108	0.7539	0.0294	0.0028	1.6073
Silverado	Tier 2	FTP	7/14/2016 9:25	0.0325	0.0534	0.6472	0.0212	0.0043	1.4249
Silverado	Tier 2	HFET	7/28/2016 13:54	0.0026	0.0030	0.2048	0.0000	0.0004	
Silverado	Tier 2	HFET	7/28/2016 14:45	0.0046	0.0040	0.2029	0.0009	0.0032	
Silverado	Tier 2	HFET	7/28/2016 15:39	0.0070	0.0047	0.2417	0.0027	0.0077	
Silverado	Tier 3	FTP	7/6/2016 7:44	0.0510	0.0113	0.5703	0.0450	0.0040	1.4320
Silverado	Tier 3	FTP	7/7/2016 13:55	0.0920	0.0144	0.7943	0.0869	0.0066	1.8988
Silverado	Tier 3	FTP	7/8/2016 7:06	0.0465	0.0125	0.6026	0.0386	0.0041	1.3235
Silverado	Tier 3	FTP	7/19/2016 13:06	0.0436	0.0115	0.6733	0.0479	0.0045	1.8905
Silverado	Tier 3	FTP	7/20/2016 7:47	0.0493	0.0115	0.4884	0.0544	0.0041	1.4426
Silverado	Tier 3	FTP	7/21/2016 13:04	0.0342	0.0115	0.5374	0.0377	0.0044	1.5833
Silverado	Tier 3	HFET	7/26/2016 9:18	0.0004	0.0012	0.2038	0.0000	0.0004	
Silverado	Tier 3	HFET	7/26/2016 10:08	0.0002	0.0011	0.1521	0.0000	0.0005	
Silverado	Tier 3	HFET	7/26/2016 11:17	0.0006	0.0014	0.1870	0.0000	0.0005	
Volvo	Tier 2	FTP	4/19/2016 13:22	0.0123	0.0036	0.3190	0.0095	0.0056	0.8402
Volvo	Tier 2	FTP	4/20/2016 7:36	0.0205	0.0041	0.4900	0.0174	0.0075	0.9924
Volvo	Tier 2	FTP	4/22/2016 7:30	0.0178	0.0038	0.5293	0.0148	0.0067	0.8195
Volvo	Tier 2	FTP	5/3/2016 7:09	0.0199	0.0033	0.4080	0.0176	0.0082	0.8560
Volvo	Tier 2	FTP	5/4/2016 12:29	0.0117	0.0036	0.4879	0.0088	0.0070	0.8440
Volvo	Tier 2	FTP	5/5/2016 7:29	0.0205	0.0033	0.5200	0.0181	0.0084	0.7952
Volvo	Tier 2	HFET	5/3/2016 9:10	0.0000	0.0005	0.2284	0.0000	0.0005	0.0406
Volvo	Tier 2	HFET	5/4/2016 13:54	0.0000	0.0005	0.2158	0.0000	0.0006	0.0542
Volvo	Tier 2	HFET	5/5/2016 8:44	0.0000	0.0004	0.2505	0.0000	0.0005	0.0680
Volvo	Tier 3	FTP	5/10/2016 10:53	0.0113	0.0040	0.5327	0.0087	0.0057	0.9388
Volvo	Tier 3	FTP	5/11/2016 7:25	0.0162	0.0037	0.5130	0.0143	0.0069	0.8453
Volvo	Tier 3	FTP	5/12/2016 13:02	0.0123	0.0036	0.4327	0.0101	0.0062	
Volvo	Tier 3	HFET	5/10/2016 13:37	0.0000	0.0003	0.2753	0.0000	0.0004	0.0352
Volvo	Tier 3	HFET	5/11/2016 8:39	0.0000	0.0002	0.2969	0.0000	0.0005	0.0203
Volvo	Tier 3	HFET	5/12/2016 14:08	0.0000	0.0002	0.2120	0.0000	0.0005	

[a] Blank values indicate that data was not collected or there was a procedural problem that invalidated the specific result but not overall test. Some missing CH_4 values for the Silverado and Civic were replaced with medians taken from similar tests on the same vehicle, as described in Section 3.3.2.