Final Technical Support Document

Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates

United States Environmental Protection Agency

Office of Transportation and Air Quality
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Assessment and Standards Division
and
Certification and Innovative Strategies Division

Office of Transportation and Air Quality
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List of Acronyms

AAA	American Automobile Association
ADFE	analytically derived fuel economy
AVTA	Advanced Vehicle Testing Activity
CAFE	Corporate Average Fuel Economy
CO	Carbon Monoxide
CO2	Carbon Dioxide
CR	Consumer Reports
CRC	Coordinating Research Council
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FTP	Federal Test Procedure
GPS	geographical positioning system
HC	Hydrocarbon
HFET	Highway Fuel Economy Test
INL	Idaho National Laboratory
LDT	light-duty truck
LDV	light-duty vehicle
LOS	level of service (volume of traffic)
MOVES	Motor Vehicle Emission Inventory System
mpg	miles per gallon
MY	model year
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NOx	Oxides of Nitrogen
NREL	National Renewable Energy Laboratory
OAP	Office of Atmospheric Programs
ORNL	Oak Ridge National Laboratory
PEMS	Portable Emissions Measurement System
PERE	Physical Emission Rate Estimator
RVP	Reid Vapor Pressure
SAFD	speed-acceleration frequency distribution
SFTP	Supplemental Federal Test Procedure
SUV	sport utility vehicle
TRLHP	tractive road load horsepower
TSD	Technical Support Document
UDDS	Urban Dynamometer Driving Schedule
VMT	vehicle miles traveled
VSP	vehicle specific power

Chapter I: Executive Summary

The EPA fuel economy estimates have appeared on the window stickers of all new cars and light trucks since the late 1970's and are well-recognized by consumers. The fuel economy estimates essentially serve two purposes: to provide consumers with a basis on which to compare the fuel economy of different vehicles, and to provide consumers with a reasonable estimate of the range of fuel economy they can expect to achieve. While the estimates historically have been a valuable tool for comparison shopping purposes, attention has been focused recently on how closely the EPA estimates approximate consumers' real-world fuel economy experience.

We are making changes to EPA's fuel economy test methods to bring the estimates closer to the fuel economy consumers are achieving in the real-world. We believe these estimates will provide car buyers with useful information when comparing the fuel economy of different vehicles. It is important to emphasize that fuel economy varies from driver to driver for a wide variety of reasons, such as different driving styles, climates, traffic patterns, use of accessories, loads, weather, and vehicle maintenance. Even different drivers of the same vehicle will experience different fuel economy as these and other factors vary. Therefore, it is impossible to design a "perfect" fuel economy test that will provide accurate real-world fuel economy estimates for every consumer. With any estimate, there will always be consumers that get better or worse actual fuel economy. The EPA estimates are meant to be a general guideline for consumers, particularly to compare the relative fuel economy of one vehicle to another. Nevertheless, we do believe that today's new fuel economy test methods will do a better job of giving consumers a more accurate estimate of the fuel economy they can achieve in the real-world.

It is essential that our fuel economy estimates continue to be derived from controlled, repeatable, laboratory tests. However, the inputs to our estimates are based on data from actual real-world driving behavior and conditions. Because the test is controlled and repeatable, an EPA fuel economy test result can be used for comparison of different vehicle models and types. EPA and manufacturers test over 1,250 vehicle models annually and every test is run under identical conditions and under a precise driver's trace, which assures that the result will be the same for an individual vehicle model no matter when and where the laboratory test is performed. Variations in temperature, road grade, driving patterns, and other variables do not impact the result of the test. While such external conditions impact fuel economy on a trip-to-trip basis, they do not change the laboratory test result. Therefore, a repeatable test provides a level playing field for all vehicles, which is essential for comparing the fuel economy of one vehicle to another. Finally, EPA must preserve the ability to confirm the values achieved by the manufacturers' testing, and this can only be achieved with a highly repeatable test or set of tests. No other fuel economy test program provides the level of repeatability as the EPA program.

However, the EPA fuel economy test methods need to reflect real world conditions as well as being a repeatable test. While some consumer groups have issued their own fuel economy numbers based on on-road driving, this approach introduces a wide number of variables – different drivers, driving patterns, weather conditions, temperatures, etc. – that make repeatability impossible. Our new fuel economy test methods are more representative of real-world conditions than the current fuel economy tests – yet we retain our practice of relying on controlled, repeatable, laboratory tests.

The methods used today for calculating the city and highway mpg estimates were established in the 1970's, and were adjusted in the mid-1980's. Since these adjustments were made, America's driving behavior has changed. In the past 20 years, speed limits have increased and vehicles have been designed for higher power – as a result, Americans are driving faster and more aggressively than ever before. Vehicle technology has changed markedly, and many more vehicles are equipped with energy-consuming accessories like air conditioning. These and other factors are not accounted for in the current test procedures used to determine the city and highway mpg estimates. Our analyses indicate that if these factors were better accounted for, the city and highway fuel economy label estimates would be generally lower and closer to the average real-world experience of consumers.

A fundamental issue with today's fuel economy estimates is that the underlying test procedures do not fully represent real-world driving conditions. Some of the key limitations are that the highway test has a top speed of only 60 miles per hour, both the city and highway tests are run at mild climatic conditions (75°F), both tests have mild acceleration rates, and neither test is run with the use of accessories, such as air conditioning. However, since the time of the last fuel economy labeling revisions in the mid-1980's, EPA has established several additional test procedures, used for emissions compliance purposes, which capture a much broader range of real-world driving conditions. Specifically, these emissions test cycles capture the effects of higher speeds, more aggressive driving (i.e., higher acceleration rates), the use of air conditioning at higher ambient temperatures, and colder temperature operation. Our analysis indicates that these factors can have a significant impact on fuel economy, and that the impacts can vary widely across different vehicles.

We are now requiring that three additional emission tests, already used by manufacturers, will be utilized to derive more accurate fuel economy estimates. These three test procedures encompass a much broader range of real-world driving, as they incorporate the effects of higher speeds, more rapid accelerations, air conditioning use, and cold temperatures. Our new approach will utilize these additional emission tests, together with the current two fuel economy tests, so that our fuel economy test methods reflect a much broader range of driving conditions.

Our final rule revises the test methods by which the city and highway fuel economy estimates are calculated. We are replacing the current method of adjusting the city (FTP) test result downward by 10% and the highway (HFET) test result downward by 22%. Instead, we are finalizing a new approach that incorporates additional test methods that address factors that impact fuel economy, but are missing from today's tests – specifically, higher speeds, more aggressive driving (higher acceleration rates), the use of air conditioning, and the effect of cold temperature. The new test methods will bring into the fuel economy estimates the test results from the five emissions tests in place today: FTP, HFET, US06, SC03, and Cold FTP.[a] Thus,

[a] The US06 test is designed to represent high speed highway driving and aggressive (i.e., rapid accelerations and decelerations) urban driving. The SC03 test is designed to represent the impact of air conditioner operation at high temperatures. The Cold FTP, which is conducted at 20°F, is designed to reflect the impact of cold temperatures.

we refer to this as the “5-cycle” method. Under this new method, rather than basing the city mpg estimate solely on the adjusted FTP test result, and the highway mpg estimate solely on the adjusted HFET test result, each estimate will be based on a “composite” calculation of all five tests, weighting each appropriately to arrive at new city and highway mpg estimates. The new city and highway estimates will each be calculated according to separate city and highway “5-cycle” formulae that are based on fuel economy results over these five tests. The conditions represented by each test will be “weighted” according to how much they occur over average real-world city or highway driving. For example, we have derived weightings to represent driving cycle effects, trip length, air conditioner compressor-on usage, and operation over various temperatures. The derivation of this methodology and the relevant weighting factors and formulae are the principal subject of this Final Technical Support Document.

We also are finalizing an additional downward adjustment to fuel economy estimates within the 5-cycle method. We put in place a downward adjustment to account for effects that cannot be replicated on the dynamometer. There are many factors that affect fuel economy that are not accounted for in any of our existing test cycles. These include road grade, wind, tire pressure, heavier loads, hills, snow/ice, effects of ethanol in gasoline, and others. We are finalizing a 9.5% downward adjustment to account for these effects. The detailed technical basis for this adjustment factor is contained in section III.A.5 of this Final Technical Support Document.

Because the 5-cycle method is inherently vehicle-specific, the difference between today’s values and the new fuel economy estimates could vary widely from vehicle to vehicle. Our new approach will result in city fuel economy estimates that are between 8 to 15 percent lower than today’s labels for the majority of conventional vehicles. The city mpg estimates for the manufacturers of most vehicles will drop by about 12 percent on average relative to today’s estimates. For vehicles that achieve generally better fuel economy, such as gasoline-electric hybrid vehicles, the new city estimates will be about 20 to 30 percent lower than today’s labels. The new highway fuel economy estimates will be 5 to 15 percent lower for the majority of vehicles, including most hybrids. The highway mpg estimates for the manufacturers of most vehicles will drop on average by about 8 percent, with estimates for most hybrid vehicles dropping by 10 to 20 percent relative to today’s estimates.

In Chapter II of this Final Technical Support Document, we compare current EPA label fuel economy values, as well as the proposed 5-cycle and mpg-based values, to several independent estimates of onroad fuel economy. The independent estimates fall into several general categories, depending on the type of data involved. One type of estimate involves the measurement or estimate of onroad fuel economy of vehicles in typical operation. Two examples in this category are the U.S. Department of Energy (DOE) FreedomCar program and the DOE Your MPG program. A second type of estimate involves onroad measurement of fuel economy according to some established protocol by an independent organization. Examples in this category are fuel economy estimates developed by Consumer Report, Edmunds, and AAA. A third type of estimate involves broad estimates of national fuel consumption and national VMT and the development of fleet-wide fuel economy estimates. Examples in this category are fleet-wide fuel economy estimates developed by Federal Highway Administration (FHWA) and the Energy Information Administration (EIA).

These estimates and studies often suggest that there is a shortfall between the EPA estimates and real-world fuel economy. For example, Consumer Reports derives city, highway, and overall fuel economy estimates, and their methods clearly demonstrate the large degree of variation across vehicles. While their city fuel economy estimates fall on average below the EPA label values, their highway estimates are, on average, higher than the EPA label values. Consumer Reports' overall fuel economy estimates range from 27% below to 20% above the EPA overall rating. The Automobile Association of America (AAA) likewise publishes the fuel economy results they achieve in their annual auto guide for new cars and trucks. In their 2004 auto guide, about half of their estimates were below the EPA combined city/highway value, and about one half were above the EPA city/highway combined value. Their estimates ranged from 40% lower than EPA's to 22% higher, again reflecting a great deal of vehicle-to-vehicle variation.

Each of these studies differs in its test methods, driving cycles, sampling of vehicles, and methods of measuring fuel economy. There are strengths and weaknesses of each study, which we discuss further in this Technical Support Document. Collectively, these studies and data indicate there are many cases where real-world fuel economy falls below the EPA estimates. The studies also indicate that real-world fuel economy varies significantly depending on the conditions under which it is evaluated. Nevertheless, taken as a whole, these studies reflect a wide range of real-world driving conditions, and show that fuel economy can be much lower than EPA's estimates if more real-world conditions are considered. Where possible, we also compare the results of these studies with the new label values that would result from the 5-cycle and mpg-based methods, and we found that in virtually every case the 5-cycle method resulted in fuel economy values that were significantly closer to these other estimates than the existing labels.

In Chapter III of this Final Technical Support Document we describe the development of the vehicle specific 5-cycle and mpg-based methods. We also evaluate the range and variability of onroad fuel economy experienced by drivers of the same vehicle and we develop an adjustment factor that accounts for fuel economy impacts not reproducible on the dynamometer or in the testing laboratory. We describe the final vehicle specific 5-cycle formulae and the final mpg-based formulae, followed by a discussion of how the current city and highway fuel economy values would change under the two methods. Finally, we evaluate the sensitivities and uncertainties in the vehicle specific 5-cycle formulae.

We describe how these different elements of our fuel economy model are developed and assembled from the test data. We develop methodologies for estimating the following:

- Fuel use related to engine start-up, or start fuel use;
- Fuel use once the engine is warmed up at 75°F (with no air conditioner operation);
- Fuel use due to air conditioner use;
- Fuel use once the engine is warmed up at colder temperatures; and
- Factors that affect onroad fuel economy but which are not addressed by any of the five dynamometer cycles.

We describe the derivation of the mpg-based approach – a simplified method that will be an interim option in the first three years of the program and an available option under certain circumstances in subsequent years. The 5-cycle fuel economy formulae assume that fuel economy estimates are available for specific vehicles for all five dynamometer cycles and their respective bags of emission measurements. As discussed in the preamble to the final rule, these estimates may be based on fuel economy measurements, or on estimates based on test results from a similar vehicle. A simplified approach to implementing the 5-cycle formulae is to apply these formulae to test results on recent model vehicles and develop correlations between the 5-cycle city and highway fuel economy estimates for these vehicles and their fuel economy over the FTP and HFET, respectively. This simplified approach is referred to as the mpg-based approach, since the resultant label adjustment will vary depending on the measured fuel economy (i.e., mpg) of a vehicle over the FTP and HFET tests, and will not require any additional tests.

Following the detailed discussion of the 5-cycle and mpg-based approaches, we present the actual formulae and an assessment of the impact our new approaches will have on fuel economy label values. The impact of today's final rule on city and highway fuel economy label values was assessed using the same database of 615 late model year vehicles used to develop the mpg-based adjustments. Use of the 5-cycle formulae will reduce both current city and highway fuel economy label values. For conventional vehicles, city and highway fuel economy values would be reduced an average of 11% and 8%, respectively. For higher than average fuel economy vehicles, the reduction in city fuel economy will be slightly higher, while for lower than average fuel economy vehicles, the reduction in city fuel economy will be slightly lower. The change in highway fuel economy is essentially independent of current highway fuel economy.

The impact on hybrid vehicles will be significantly greater for city fuel economy, averaging a 22% reduction. However, the reduction in highway fuel economy will be similar, but toward the higher end of the range as for conventional gasoline-fueled vehicles. The impacts of the 5-cycle formulae on the single diesel vehicle in the database are very similar to those for conventional gasoline fueled vehicles.

In Chapter IV we detail our estimates of the cost impacts of our new regulation. For model years 2008 through 2010, manufacturers may use the mpg-based calculation for the five-cycle fuel economy values or they may conduct voluntary 5-cycle testing. For model years 2011 and after, if the five-cycle city and highway fuel economy values for an emission data vehicle group are not more than 4% and 5% below the mpg-based regression line, respectively, then all the vehicle configurations represented by the emission data vehicle (e.g., all vehicles within the vehicle test group) could continue to use the mpg-based approach. Vehicles within a test group falling more than 5% below the tolerance band for highway fuel economy values would be required to conduct US06 tests; those falling more than 4% below the city fuel economy tolerance band would be required to conduct SC03, US06, and Cold FTP tests. In addition, we expect that some of these vehicles falling below the tolerance levels may be eligible to estimate fuel economy for a given test through the application of analytically derived fuel economy (ADFE) values. Some data is currently available for vehicles that have conducted all five tests; based on this data, EPA has estimated the number of vehicles for which additional testing would be required because they fall below the 4 and 5% tolerance bands.

We prepared a range of burden estimates for this analysis, estimating minimum and maximum cost scenarios. These low and high estimates are intended to be our estimate of the outer boundaries of the likely testing and information costs. Aggregate annual costs are estimated to be between $1.4 and $1.7 million. A complete discussion of how these costs were estimated is in Chapter IV of this Technical Support Document.

Table I-1 Aggregate Costs

	MY 2008 through MY 2010		MY 2011 and After	
Cost Element	Minimum	Maximum	Minimum	Maximum
Test Volume	$0	$0	$343,000	$424,000
Facilities	$0	$0	$375,000	$560,000
Startup	$659,000	$748,000	$659,000	$748,000
TOTAL	**$659,000**	**$748,000**	**$1,377,000**	**$1,731,000**

Chapter II: Current and Proposed Label Values Compared to Onroad Estimates

A. Onroad Fuel Economy Estimates During Typical Operation

In the 1984 label adjustment rule, EPA was able to compare fleetwide estimates of a variety of city and highway fuel economy label options to a number of independent estimates of onroad fleet fuel economy. In the late 1970's and early 1980's, EPA and several auto manufacturers had collected onroad fuel economy estimates from tens of thousands of drivers which could be compared to the EPA city and highway fuel economy labels. EPA primarily used the driver-based fuel economy estimates to develop the current 10% and 22% adjustments to fuel economy over the FTP and HFET, respectively.

It is not possible to repeat this type of comparison today, as the auto manufacturers no longer conduct the extensive monitoring of fuel economy that was performed in the late 1970's and early 1980's. At the same time, we have discovered three new sources of similar information. One, Oak Ridge National Laboratory (ORNL) has recently begun a program where drivers can submit their own fuel economy measurements via the Internet. This program is referred to as "YourMPG." Two, DOE has also been operating an extensive hybrid demonstration project for a few years as part of their Freedom Car project. This program carefully monitors both VMT and fuel consumption, so accurate fuel economy estimates are available for a number of hybrid vehicles. Three, a private survey firm, Strategic Visions, performs two surveys of new vehicle purchasers a year to assess consumer satisfaction. The survey includes questions regarding the fuel economy being achieved to date. We have purchased the Strategic Visions survey results for model years 2004-06. The results of our analysis to date are discussed below.

In addition to these three programs, EPA conducted it own testing of vehicle fuel economy in Kansas City, in conjunction with cooperative efforts between EPA and the Coordinating Research Council (CRC). The state of California, in conjunction with automobile manufacturers and others have been obtaining vehicle operational data via chase car studies. All of these studies are discussed below.

1. ORNL "YourMPG" Program

The ORNL YourMPG data are similar in nature to the much larger databases analyzed for the 1985 label adjustment rule. Drivers measure their own fuel economy and provide a perceived split of their driving into city and highway categories. The strength of this type of data is the fact that the vehicle is being operated by the owner or regular driver in typical use. The weaknesses are the unknown representativeness of the sample, the unknown nature of the technique used by the owner/driver to measure fuel economy and the unknown time period over which fuel economy is generally assessed (e.g., a couple of tanks full or the past year). In the particular case of the ORNL database, its current size is still small (8180 estimates of fuel economy for 4092 vehicles) compared to those available in 1985, though it is growing daily.

We compared the fuel economy estimates submitted to the ORNL website with each vehicle's fuel economy label. We combined the city and highway labels using each driver's estimate of the percentage which was city and highway. If a driver did not provide an estimate of the breakdown of their driving pattern, we assumed that their driving was 55% city and 45% highway with respect to the current label values and 43% city and 57% highway with respect to the mpg-based label values. We conducted separate comparisons for conventional gasoline vehicles, conventional vehicles with relatively high fuel economy, hybrids and diesels. The results are shown below.

Table II.A-1. YourMPG Versus Current EPA Label Fuel Economy

Vehicle Type	No. of Estimates	YourMPG	Current Label	Difference	MPG-Based Label	Difference
Conventional Gasoline	7330	23.8	24.1	-1.4%	21.7	9.1%
High MPG Conventional Gasoline*	680	35.1	35.8	-1.7%	31.6	11.2%
Hybrid Gasoline	520	43.2	47.1	-8.2%	40.5	6.3%
Diesel	221	41.8	40.1	4.3%	35.3	18.3%

* Combined EPA Label fuel economy value of 32 mpg or greater, representing about the top 10% fuel economy conventional vehicles.

As can be seen, diesels appear to perform the best with respect to their label fuel economy, outperforming the label by 4.3%. Conventional gasoline vehicles come very close to meeting their label, falling short by only 1.4%. Conventional vehicles with relatively high combined fuel economy (here assumed to be 32 mpg or more, representing the top 10% of conventional vehicles in terms of fuel economy) performed only slightly worse, falling short by 1.7%. Hybrids fall short by a much larger margin, 8.2%. Thus, the greater shortfall seen with hybrids appears to be more related to hybrid technology than to simply high levels of fuel economy.

With respect to the mpg-based label values, diesels still perform the best of the four types of vehicles, now exceeding their label values by 18%.[b] Those conventional vehicles with relatively high fuel economy fall next, followed by the typical conventional vehicle and hybrids. Thus, the YourMPG estimates indicate that hybrid performance differs from that of conventional vehicles, including those with high fuel economy.

[b] There is a larger apparent difference between the mpg-based label values and the current label values in Table II.A.2 than the 6% average impact of the mpg-based approach on current label values cited elsewhere in this Final Technical Support Document . This occurs because when working with the YourMPG estimates, we are using the driver's estimate of city/highway driving breakdown in all cases. When speaking of combined label values, however, we use a 55/45 breakdown for the current label values and a 43/57 breakdown for the mpg-based values. The lower city driving weight in the mpg-based formula increases the combined value relative to that for the current label values and reduces the difference between the two approaches.

The YourMPG database also provides us with an estimate of drivers' perception of the type of driving which they perform. On average, they estimated that 43.2% of their driving was city driving and 56.8% was highway. These two figures are essentially identical to the weights developed from the Draft MOVES2004 depiction of onroad driving and embedded in the 5-cycle combined fuel economy formula. This is encouraging. However, this change from the traditional 55/45 city/highway split of onroad driving also causes some unusual relationships between onroad and label fuel economy as depicted in Table II.A-1 above.

Focusing on conventional vehicles, which comprise the great majority of the database, Table II.A-1 shows that people's onroad fuel economy is only 1.4% lower than the current label values indicates and 9.1% higher than the mpg-based label values would have been. If a 55/45 split would have been used with the current label values, onroad fuel economy would have been 1-2% higher than the label values for these vehicles. This differs dramatically from the onroad fuel economy shortfall indicated by the FHWA estimates of onroad fuel economy discussed in Section II.C below. In other words, the YourMPG database indicates that onroad fuel economy is exceeding the standard 55/45 label fuel economy, while FHWA indicates the opposite. Examining the YourMPG database further, we found that the average 55/45 label value in the database was 25.4 mpg. Per MOBILE6.2, the average 55/45 label value of the onroad vehicle fleet is 21.2 mpg. Thus, people submitting their onroad fuel economy estimates to the YourMPG database drive more fuel efficient vehicles than the average vehicle. This could indicate that those participating in the program have a greater interest in reducing fuel consumption than the average driver, but this cannot be known for certain. However, if true, this would explain the difference seen between the YourMPG database and the FHWA fleetwide estimates.

2. DOE FreedomCar Program

The Department of Energy has overseen the real world operation of a number of electric hybrid vehicles for a period of years. The Advanced Vehicle Testing Activity (AVTA), conducted jointly by the Idaho National Laboratory (INL) and the National Renewable Energy Laboratory (NREL), has been benchmarking hybrid electric vehicle performance as part of the FreedomCAR & Vehicle Technologies Program. The strength of the FreedomCAR program testing of hybrid vehicles lies in the fact that the vehicles are operated on the road over long term periods similar to what consumer-purchased vehicles experience, albeit often in commercial applications. Over a million miles of operation have been assessed and careful fuel consumption and mileage records are kept. The weaknesses are that some of the vehicles are in commercial use (e.g., company pool vehicles) for accelerated mileage accumulation and that the vehicles are operated exclusively in the Southwest, mainly in Phoenix, Arizona and surrounding areas. Nevertheless, the vehicles are operated just as any other vehicle would be in that application and the vehicles are subject to all of the environmental and roadway factors which affect the fuel economy of typical vehicles, such as winds, rough roads, hills, traffic congestion, etc. Because of the limited geographic area of the program, the vehicles are more likely to experience hot temperatures and air conditioning use than cold temperatures.

The vehicles' operators report mileage and fuel usage to FreedomCAR which posts the monthly and cumulative fuel economy of each electric hybrid fleet on a monthly schedule.

Therefore, seasonal changes in fuel economy can be observed. The results of the fleets are shown in Table II.A-2.

Table II.A-2. FreedomCAR Hybrid Fleet Cumulative Versus EPA Composite Label Fuel Economy

			Fuel Economy (mpg)				Difference (%)		
Vehicle	Accumulated Mileage	Fleet Size	Onroad	EPA Composite Label *					
				Current	5-Cycle	MPG-Based	Current	5-Cycle	MPG-Based
2001 Honda Insight	417,000	6	45.2	61.0	50.4	51.5	35%	12%	14%
2002 Toyota Prius	458,000	6	41.0	48.6	----	----	19%		
2003 Honda Civic	378,000	4	37.6	46.3	37.9	39.7	23%	1%	6%
2004 Toyota Prius	186,000	2	44.9	54.6	44.1	45.5	22%	-2%	1%
2004 Chevrolet Silverado 2wd	48,000	1	17.7	18.8	----	----	6%		
2004 Chevrolet Silverado 4wd	53,000	1	17.9	16.9	15.1	15.2	-6%	-16%	-15%
2005 Ford Escape 2wd	70,000	1	28.6	33.6	----	----	17%		
2005 Ford Escape 4wd	78,000	1	27.0	29.9	23.6	26.1	11%	-13%	-3%
2005 Honda Accord	158,000	2	27.8	32.3	25.9	28.3	16%	-7%	2%
2005 Lexus RX400h	67,000	2	24.8	28.1	24.0	24.4	13%	-3%	-2%
2006 Toyota Highlander	69,000	2	24.7	28.1	24.0	24.4	14%	-3%	-1%
Average	180,000	2.5	30.7	37.0	31.6	32.9	16%	-3%	1%

* Current combined is a 55/45 weighting of city/highway fuel economy. Combined 5-cycle and mpg-based fuel economy is a 43/57 weighting of city/highway fuel economy. All label values from EPA certification database. Current combined label fuel economy values shown will not match official label values due to differences in vehicle configurations. The FreedomCAR fleet information as reported thru August 2006.

As can be seen, EPA's current label formulae over-estimate the onroad fuel economy achieved by all but one of the hybrid vehicle fleets. It should be noted that the values for current combined fuel economy are those from EPA's certification database and are not the official label values. The official label values are even higher due to differences between the worse case vehicles tested over the Supplemental FTP cycles and the average vehicle sold. The largest shortfall was 35% for the Honda Insights. The Chevrolet Silverado was the only model which exceeded the current label value of the test vehicle in our certification database. This is likely related to the fact that its hybrid design includes limited fuel economy targeted features. Except for the Chevrolet Silverado, the onroad fuel economy for each fleet never exceeded either the city or highway fuel economy label. This indicates that regardless of whether the vehicles were driven predominantly in city or highway driving modes, other real world factors reduced onroad fuel economy beyond that captured in the FTP and HFET and the current 10% and 22% adjustment factors.

Table II.A-2 also presents combined fuel economy values using the final 5-cycle and mpg-based formulae for those vehicles for which we have 5-cycle fuel economy data. The final combined 5-cycle label values exceed onroad fuel economy for two out of eight models, while the final mpg-based values do so for four out of eight models. The average of the differences is very small in both cases. On average, the combined 5-cycle value is 3% lower than those measured onroad. However, as mentioned above, the specific vehicles in our 5-cycle database tend to be worse case. For example, the current official label values exceed those shown in Table II.A-2 by 3%. If we increased the combined 5-cycle values commensurately, they would match the onroad values on average. Thus, while both of the final approaches do a much more reasonable job at predicting the onroad fuel economy achieved in the DOE FreedomCar program than the current label formulae, the final 5-cycle formulae appear to be particularly accurate when compared to the FreedomCar experience.

The close match between the final 5-cycle formulae and the FreedomCar experience is somewhat fortuitous, as the climate where the vehicles were primarily driven is not typical of most of the U.S. The FreedomCar program focuses on the southwest U.S. There, air conditioning use is much higher than average, while cold temperature operation is much lower than for the U.S. on average. While both factors reduce fuel economy, they do so to different extents. Colder temperatures have a much larger impact on national average, 5-cycle fuel economy than air conditioning. In projecting 5-cycle fuel economy values for individual vehicles, we have had to estimate the impact of heater-defroster operation on fuel economy during the cold FTP. For conventional vehicles, the effect is likely very small (i.e., less than 2%). However, for a couple of hybrids tested, the effect was much larger. The impact of heater-defroster operation is likely to vary significantly across individual hybrids, but without data, we cannot anticipate this variability. Overall, basing this impact on the two hybrids tested reduced the combined 5-cycle fuel economy of the hybrids in our certification database by 3%. Clearly this change is not relevant in areas like Phoenix. This simply indicates the limitations involved in very direct comparisons of vehicle test programs and 5-cycle fuel economy estimates. Overall, the fact that both the final mpg-based equations and 5-cycle formulae yield fuel economy label values quite close to the FreedomCar findings is very encouraging and the best that one could hope for without fine-tuning the 5-cycle formulae to exactly match the driving activity and conditions of the FreedomCar vehicles.

When analyzing monthly reported fuel economy, large seasonal fluctuations in fuel economy were observed on most of the hybrid fleets. The seasonal fluctuations are especially noticeable on the fleets that had been in service for over one year. The fuel economy during the hot and often humid summer weather months when heavy air conditioning usage could be expected was as much as 15 mpg lower than observed fuel economy during mild Phoenix area winter months. Fuel economy over the SC03 air conditioning test for the three hybrids with the highest rated fuel economy shown in Table II.A-2 (Prius, Insight and Civic) tends to be 15-20 mpg lower than that over the FTP. No cold weather operation similar to northern states or the Cold FTP (20°F) was reported which would likely have resulted in further shortfalls.

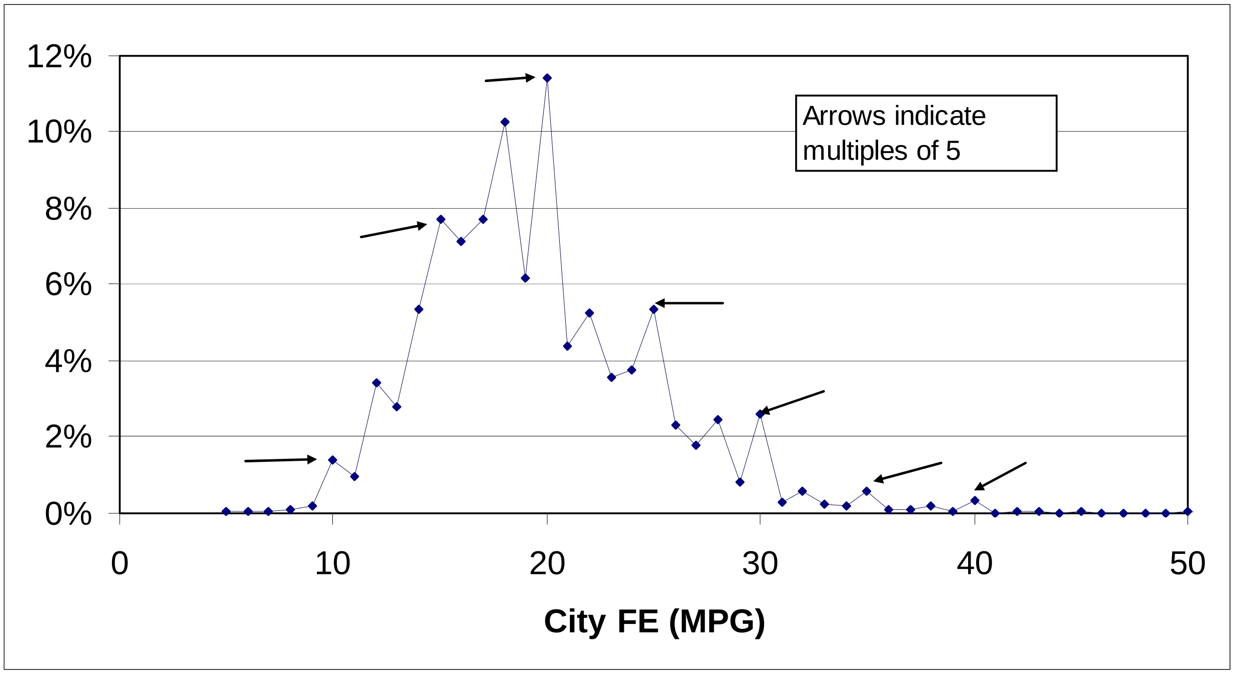
3. Strategic Visions New Vehicle Survey

Strategic Visions surveys roughly 100,000 purchasers of new cars and light trucks each year. The survey recipients are selected randomly from among the purchasers of each vehicle model and therefore represent all regions of the country. Some models are more heavily surveyed than others, particularly models which have just been introduced or significantly redesigned. Therefore, the results should be assessed on a model by model basis and not averaged across models before averaged within each model.

The survey asks recipients to write down the fuel economy which they are currently achieving. About half of the recipients respond to the request for fuel economy information. Thus, about 50,000 estimates of onroad fuel economy are received each year. The strengths of this survey are the large number of estimates and the fact that the survey recipients are randomly selected. The weaknesses are the unknown source of each consumer's fuel economy estimate and the survey response rate for this question (i.e., only 50%). Still the fact that a wide range of models are surveyed with each model having a number of independent estimates allows very direct comparison to the current, 5-cycle and mpg-based label values on a model by model basis.

EPA purchased the Strategic Visions survey results for the 2004-06 model years. In preparing the data for analysis, we noticed a peculiarity. The frequency of consumers' estimated fuel economy for fuel economy values being a multiple of five were much higher than those with other values. Figure II-1 shows the distribution of estimated city fuel economy for 2006 model year vehicles.

Figure II-1. Distribution of Onroad Fuel Economy Estimates – Strategic Vision, 2006



As can be seen from Figure II-1, each of the frequencies of fuel economy values ending in 5 or 0 is much higher than those of nearby values. By comparing the difference between the frequencies of fuel economy values of a multiple of five with those just above and below that value, we estimate that there is an excess response of 13% for fuel economy values of a multiple of five compared to other values. This implies that 13% of the respondents were only estimating their onroad fuel economy to within ±5 mpg. We found the same effect with highway fuel economy estimates. Thus, it is very likely that the same respondents rounded both their city and highway fuel economy estimates to a factor of five.

It is unknown whether this tendency biases the estimated onroad fuel economy upward or downward. However, the presence of such rough estimates significantly reduces the value of this database to distinguish between two sets of fuel economy estimates. This is particularly true for comparisons between the mpg-based and 5-cycle formulae, which often only differ by 1-2 mpg. We are working with Strategic Visions to better identify the method used by respondents to estimate their onroad fuel economy so that we can focus on those who actually kept mileage and fuel usage records. This should also avoid those respondents who estimate, versus measure, their actual fuel economy. We plan to analyze this improved data over the next couple of years.

4. Kansas City Instrumented Vehicle Study

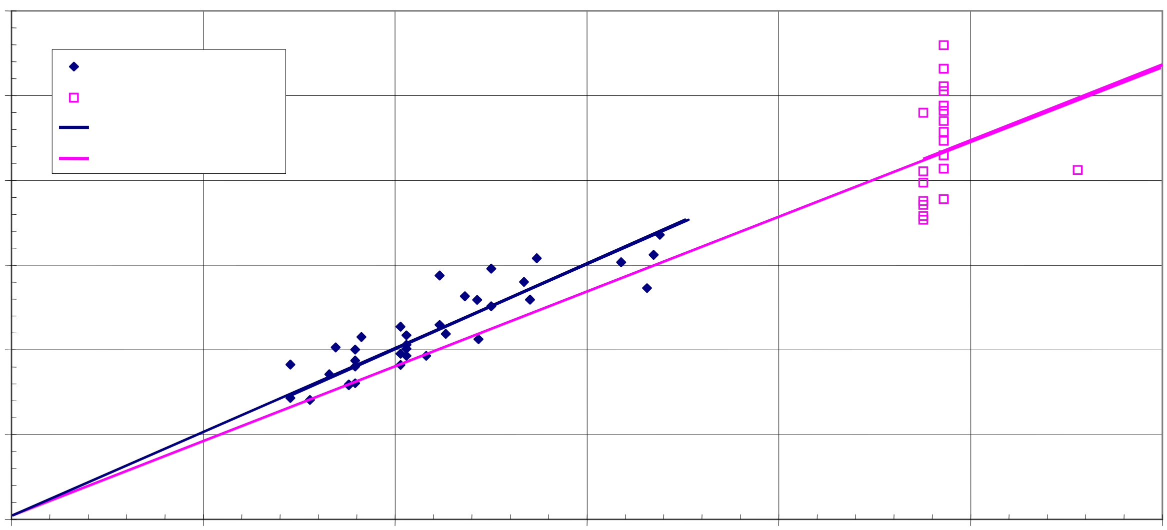
During 2004–2005, EPA in association with the Coordinating Research Council, DOT and DOE, recruited and tested over 600 privately owned passenger vehicles in the Kansas City area. The vehicles included an assortment of compact cars, mid-size cars, pick-ups and SUVs from a variety of manufacturers. The program was split into 3 rounds (1, 1.5 and 2), each consisting of 120-300 vehicles. In all three rounds, vehicles were recruited randomly from lists of vehicle registrations in the Kansas City area. Care was taken to ensure that the sample were random with respect to the geographic location of the owner and socio-economic status. In rounds 1 and 2, the desired sample of vehicles was stratified into four groups of model years, with emphasis on older vehicles[1,2]. The primary purpose of Rounds 1 and 2 was the quantification of particulate emissions, particularly those from high emitters. In Round 1.5, only 2001 and later model year vehicles were sampled. (Details about the design and performance of Round 1.5 are described the study's final report.[3]) The primary purpose of Round 1.5 was the measurement of onroad fuel economy from vehicles for which we could estimate 5-cycle fuel economy. This meant that we had to have fuel economy estimates over all five cycles for these vehicles (i.e., that the vehicle had to be certified to the Supplemental FTP standards). These standards began phasing in with the 2001 model year.

Only a few of the vehicles tested in Rounds 1 and 2 were instrumented with a Portable Emissions Measurement System (PEMS) and tested in the hands of their owners. As these vehicles ranged in model year from 1968 to 2005, very few of the vehicles tested in Rounds 1 and 2 had been certified to the Supplemental FTP standards. However, all of the vehicles tested in Round 1.5 were instrumented with PEMS and had their fuel economy measured while being driven in normal use by their owners. The round 1.5 vehicle fleet consisted of approximately 120 vehicles, including over 30 hybrid electric vehicles. The PEMS measures driving activity, as well as second-by-second mass emissions of CO_2, CO, HC, and NO_X for roughly 24 hours while the owners of the vehicles are utilizing their vehicles on the road under normal, real-world conditions.

Total fuel consumption for each vehicle was determined from the carbon balance of the CO_2, HC, and CO emissions. (Details of the test program and the methods used to process the data obtained are described in Appendix A of this Final Technical Support Document.) Each vehicle's fuel was sampled and tested for density and weight percent carbon. The total distance of driving was determined by summing vehicle speed and multiplying by total time of operation. This total distance traveled was then divided by total fuel consumption to determine onroad fuel economy.

EPA city and highway label fuel economy values were obtained from EPA mileage guides. The test vehicles were matched to those tested in Kansas City to the closest degree possible. Figure II-2 compares the measured fuel economy to the 55/45 composite label fuel economy from Round 1.5 (newer vehicles). We segregated the vehicles into two groups: conventional gasoline-fueled vehicles and hybrids. A linear regression with no constant of the conventional vehicles showed nearly one-to-one correlation, with a slope of 1.006. The correlation was also quite good (r-squared value of 0.77). The largest difference was only 6 mpg, or about 30%. Thus, the onroad fuel economy data indicate no offset from the current EPA label values on average.

Figure II-2. Comparison Onroad to Current Label Economy: Kansas City



The correlation of hybrid data shows much more scatter. This is partially explained by the fact that only three hybrid models were tested, a number of Toyota Prius and Honda Civic vehicles and one Honda Insight. The range of fuel economy label values for these three vehicles is very small, 48-56 mpg, plus one vehicle at 64 mpg. With the high degree of variability in measured onroad fuel economy, it is not surprising that the correlation coefficient was small.

On average, hybrid fuel economy was 11% less than the composite EPA label values. The average onroad fuel economy of the Toyota Prius vehicles was closer to their composite label values than those for the two Honda models. On average, the onroad fuel economy of the hybrids tested varied more than the conventional vehicles. This could be due to hybrids' greater sensitivity to operating conditions which can either take full advantage of the hybrid technology or essentially nullify it. The fact that many vehicles started out testing with a hot start likely biased onroad fuel economy upwards to some degree. Thus, the actual shortfalls found would have been greater to some degree if testing had begun with a cold start.

We also performed a regression of onroad fuel consumption per mile versus the inverse of the current fuel economy value for hybrid vehicles, as Honda suggested in their comments (see Section 5.5 of the Response to Comments document). First, we found that the intercept was not statistically significant (p-value of 0.684). Thus, we performed a new regression with an intercept of zero. We found an r-squared value of 0.18, which is not much different than that for the regression of fuel economy. The slope of the regression was 1.135, indicating that the hybrids consumed 13.5% more fuel than predicted by the inverse of their label values. More importantly, this slope had a p-value of 10^{-31}, indicating that it was extremely unlikely to be zero. The 95% confidence interval for the slope ranged from 1.09 to 1.18. Thus, on average, the data collected in Kansas City indicate that the hybrid vehicles tested did not perform as well as the conventional vehicles compared to their current fuel economy label values.

B. Fuel Economy Estimates by Independent Organizations

Several consumer organizations perform their own fuel economy assessments. Of these, the American Automobile Association (AAA) and Consumer Reports (CR) have tested the greatest number of vehicles. The relative strengths of this testing include the fact that the vehicles are tested on actual roads, usually in traffic and under real environmental conditions. The primary weaknesses of this testing include:

1) The fact that the drivers or driving patterns involved are not typically published, so they may or may not be representative of average U.S. drivers or driving,

2) Vehicles are tested throughout the year, so some vehicles are tested in hot weather and other in cold weather and some under moderate conditions, and

3) In some cases, the actual test procedures used to measure the volume of fuel consumed during the test are not described, leaving some doubt as to their accuracy. Still, because of the public interest in these estimates, we believed that they should be considered here. We will begin with an analysis of the Consumer Reports estimates, followed by those of Edmund's and AAA.

1. Consumer Reports Estimates of Onroad Fuel Economy

Consumer Reports published their fuel economy estimates for 303 2000-2006 model year vehicles. They publish both EPA's current city, highway and combined fuel economy estimates, as well as their own city, highway and combined fuel economy estimates. Therefore, we can compare EPA's current label values to those of CR for all 303 vehicles. As the mpg-based formulae only require knowledge of fuel economy over the FTP and HFET, we can apply these formulae to the EPA city and highway fuel economy values presented by CR (after removing the current label adjustments of 10% and 22%) and calculate mpg-based fuel economy values for all 303 vehicles. We were also able to match 70 of these vehicles with those in our 5-cycle fuel economy database.[c] Thus, for these 70 vehicles, we were able to calculate 5-cycle fuel economy values.

We made two sets of comparisons. One set included all 303 vehicles. The other set included only 70 vehicles. The results of the first comparison are shown in Table II.B-1.

Table II.B-1. Consumer Reports and Current EPA and MPG-Based Fuel Economy: 303 Vehicles

	Consumer Reports	Current EPA Label		MPG-Based	
	MPG	MPG	Difference *	MPG	Difference
City	14.2	20.4	-30%	18.0	-21%
Highway	29.3	26.9	9%	24.7	19%
Combined	20.7	22.9	-9%	21.2	-3%

* Consumer Reports fuel economy compared to EPA label value.

As can be seen, the CR city fuel economy values are well below both the current label or mpg-based label values (21% to 30%). The reverse is true for highway fuel economy. The CR estimate of combined fuel economy is 9% lower on average than the 55/45 composite of the current EPA city and highway label values. However, the CR estimate of combined fuel economy is only 3% lower on average than the 43/57 composite of the mpg-based city and highway fuel economy values. Thus, there is a much better match up between the composite mpg-based fuel economy and the CR combined fuel economy than with current label values.

Table II.B-2 presents the same comparisons, except that it includes the 5-cycle estimates and only includes the 70 matched vehicles.

Table II.B-2. CR and Current EPA, 5-Cycle and MPG-Based Fuel Economy: 70 Vehicles

	Consumer Reports	Current EPA Label		5-Cycle		MPG-Based	
	MPG	MPG	Difference*	MPG	Difference	MPG	Difference
City	14.3	20.4	-30%	18.0	-21%	17.8	-20%
Highway	29.3	26.4	11%	24.3	21%	24.1	22%
Combined	20.6	22.7	-9%	21.0	-2%	20.9	-2%

* Consumer Reports fuel economy compared to EPA label value.

As can be seen, the comparisons between the CR, current EPA and mpg-based fuel economies are very similar to those in Table II.B-1. On average across 70 vehicles, the CR combined fuel economy estimates differ from the current, mpg-based and 5-cycle combined fuel economy

[c] In the Draft Technical Support Document , we identified 151 vehicles which were both tested by Consumer Reports and in our certification database. However, many of these matching vehicles were not from the same model year.

values 9%, 2%, and 2%. The standard deviations of the percentage differs for individual models provides an indication of the consistency in the offset, or in the ability of the various label approaches to predict relative fuel economy differences between models. Across 70 vehicles, the standard deviation of the percentage differences between the CR combined fuel economy estimates and the current, mpg-based and 5-cycle combined fuel economy values are 6.5%, 6.6%, and 6.3%. These standard deviations are very similar. The 5-cycle label values provide slightly better estimates of relative vehicle fuel economy than the other two label approaches. As mentioned above, the CR test procedures do not include cold starts or air conditioning operation. As these are two important features of the 5-cycle formulae, much of the potential improvement associated with the 5-cycle approach is not reflected in CR's fuel economy estimates.

Of particular interest here are the fuel economy values for hybrid vehicles. For hybrids, the 5-cycle and mpg-based formulae often give different results. The 303 vehicles tested by Consumer Reports include six hybrid vehicles. We have 5-cycle fuel economy estimates for four of these vehicles, all except the 2001 Prius and 2000 Insight . A comparison of the various fuel economy estimates for the five hybrids values are shown in the Table II.B-3. To make the comparison between the three label approaches as equitable as possible, we show based the current label values on the FTP and HFET fuel economy values in the 5-cycle fuel economy database and not those shown in the CR report.

Table II.B-3. Comparison of Consumer Reports and EPA Fuel Economy Values for Hybrids

	Consumer Reports	Current EPA Label		5-Cycle Fuel Economy		MPG-Based Fuel Economy	
	MPG	MPG	Difference	MPG	Difference	MPG	Difference
City Fuel Economy							
Escape	22	32	-31%	27	-20%	23	-4%
Accord	18	30	-39%	26	-29%	22	-18%
Civic	26	47	-44%	38	-32%	34	-24%
2005 Prius	35	57	-38%	45	-23%	45	-22%
Average	**25**	**41**	**-38%**	**34**	**-26%**	**31**	**-17%**
Highway Fuel Economy							
Escape	29	28	5%	25	14%	24	20%
Accord	37	36	2%	33	12%	30	25%
Civic	45	46	-2%	41	9%	39	15%
2005 Prius	50	50	0%	45	12%	45	10%
Average	**40**	**40**	**1%**	**36**	**12%**	**35**	**17%**
Combined Fuel Economy							
Escape	26	30	-13%	26	-1%	24	10%
Accord	25	32	-23%	29	-15%	26	-3%
Civic	36	46	-22%	40	-10%	37	-2%
2005 Prius	44	54	-18%	45	-2%	45	-2%
Average	**33**	**41**	**-19%**	**33**	**-7%**	**0**	**1%**

A lot of information is presented in Table II.B-3. We will focus first on the results for all five hybrids averaged together, indicated in bold in the table, starting with the city, then the highway, then the combined fuel economy estimates.

Starting with the city values, the CR city fuel economy estimates average 38% less than the current EPA city label values. This is greater than for the average vehicle, where the difference was 30%. The differences are smaller for the mpg-based and 5-cycle city values (26% and 17%, respectively). While the 26% difference for the mpg-based approach is greater than that for the average vehicle (21%), the 17% difference for the 5-cycle approach is less than that for the average vehicle (20%). This indicates that the 5-cycle formula for city driving is likely reflecting factors which are included in CR's city test protocol and which are not included in the FTP, nor a constant 10% adjustment factor. In contrast, the current and mpg-based label approaches do not. While the mpg-based formula for city driving produces fuel economy estimates more closely resembling those of CR than the current label values, the mpg-based city formula does not pick up factors which are apparently unique to hybrids which are included in CR's test procedure.

With respect to highway fuel economy, as described earlier for conventional vehicles, the CR highway fuel economy estimates tend to be much higher than all the label approaches (as opposed to the CR city fuel economy estimates, which tend to be much lower than all the label approaches). However, except for this fundamental shift, the relative performance of the three label approaches with respect to CR highway fuel economy estimates is the same for city and highway fuel economy. The current and mpg-based approaches predict greater relative fuel economy benefits for hybrids that the CR highway testing is not finding. In contrast, the benefits of hybrid technology on highway fuel economy as indicated by the 5-cycle formulae are reflected in the CR testing.

Again, the story is similar for the combined label values. The current and mpg-based label approaches average 27% higher than CR's combined values for the five hybrids. This is more than twice the difference for the average vehicle, where the difference was only 11%. Again, this difference in combined values indicates that the current EPA label formulae are granting some relative benefits to hybrid vehicles which are not reflected in CR's combined test protocol. The 5-cycle combined values average 5% higher than the CR combined values, which is only 2% more than the 3% difference found for 70 vehicles. This indicates that the 5-cycle formula on a combined driving basis is only granting a very slight relative benefit to hybrid vehicles compared to CR's combined test protocol. In contrast, the mpg-based equations appear to be granting hybrids a greater relative benefit compared to the CR test protocols. The mpg-based combined fuel economy averages 8% higher than the CR values for the five hybrids, while only 2% for the 70 and 303 vehicle fleets.

Fourth, moving to the comparison of combined fuel economy for individual hybrid vehicles, the differences between the three "EPA" estimates and the CR estimates tend to be consistent in percentage terms, with the exception of the Escape and to some extent, the Accord. The differences for these two hybrids are not surprising. The other hybrids have very high fuel economy values compared to conventional vehicles. Thus, they essentially "set" the mpg-based equations for their range of fuel economy. The fuel economies of the Escape and the Accord fall within the range of conventional vehicle fuel economy. Here, the mpg-based equations are "set" by the more numerous conventional vehicle data.

Overall, fuel economy estimates based on the 5-cycle and mpg-based formulae both match the CR test results more closely than the current label values for conventional vehicles, which dominate the 70 and 303 vehicle samples. In addition, hybrid fuel economy estimates based on the 5-cycle formulae more closely match those of CR compared to either the current label or mpg-based formulae. The CR estimates do not necessarily match those of the average driver. Their driving cycles, in particular, are only generally described. Still, they represent an ostensibly consistent set of estimates. The CR test procedures find a lower benefit to hybrid technology than the FTP and HFET indicate. The 5-cycle formulae perform similarly, though to a slightly less extent (i.e., 2%).

Of additional interest is whether the performance of hybrids is due to their relatively high fuel economy or to their hybrid technology. To shed some light on this question, we compared the mpg-based label values to the Consumer Reports fuel economy values for all conventional vehicles, the top ten percentile (in terms of combined current label values) of all conventional vehicles and hybrids. As described above in Table II.B-1, the mpg-based combined label values averaged 2% higher than the combined fuel economy measured by Consumer Reports. The mpg-based combined label values for the top 10 percentile of conventional vehicles matched the combined fuel economy measured by Consumer Reports, those performing better than conventional vehicles as a whole, at least in terms of Consumer Reports fuel economy measurements. However, as shown in Table II.B-3 above, the mpg-based combined label values for hybrids averaged 8% higher than the combined fuel economy measured by Consumer Reports. Thus, hybrids performed worse in the Consumer Reports testing than the average conventional vehicles and worse to a slighter greater degree than those conventional vehicles with the highest fuel economy. Thus, based on the Consumer Reports testing, the differential performance of hybrids appears to be more related to their hybrid technology than to their relatively high fuel economy. The same relationships hold for the 5-cycle fuel economy values.

2. AAA Estimates of Onroad Fuel Economy

The American Automobile Association (AAA) also develops its own fuel economy estimates. In their 2004 report, AAA presented their test results and the EPA label values for 163 models. AAA only presents a single fuel economy estimate, which we understand to be a composite of city and highway operation.

Overall, AAA found a higher overall fuel economy than the current combined EPA label value for 85 models, and lower fuel economy for 73 models. On average, the AAA fuel economy estimates were 1.5% lower than the current combined EPA label values. We calculated an mpg-based 43/57 combined fuel economy using the mpg-based equations. (FTP and HFET fuel economy values were back calculated from the current EPA fuel economy label values.) On average, the AAA fuel economy estimates were 5.3% higher than the mpg-based combined fuel economy values. Table II.B-4 shows these comparisons.

Table II.B-4. AAA and Current EPA, 5-Cycle and MPG-Based Fuel Economy Estimates

	AAA	Current EPA Label		5-Cycle		MPG-Based	
	MPG	MPG	Difference*	MPG	Difference	MPG	Difference
163 vehicles	21.7	22.1	-1.5%	N/A	N/A	20.6	5.3%
61 vehicles	23.2	23.4	-0.4%	21.7	6.7%	21.9	6.1%

We were able to match 61 out of the 163 AAA-tested vehicles with similar vehicles in our 5-cycle certification database. This is lower than the 98 models which we matched in the analysis described in the Draft Technical Support Document . The lower figure is due to the use of a more stringent criterion that the vehicles match in terms of model year. (We assumed that all of the vehicles tested by AAA were 2004 model year vehicles.) As was the case with the Consumer Reports data, the FTP and HFET fuel economies for the certification vehicles in our

5-cycle fuel economy database were generally lower than those tested by AAA. Thus, we adjusted the 5-cycle city and highway fuel economy values using the ratio of the FTP and HFET fuel economy values, respectively, from our certification database and the AAA database. On average, the AAA estimates were 6.1% higher than the combined, 5-cycle fuel economy values for these 61 vehicles. On average, the AAA estimates were 6.7% higher than the combined mpg-based fuel economy values for these 61 vehicles, just slightly greater than with the 5-cycle formulae. While not shown in the table, the standard deviation of the percentage differences is 9% for all three EPA label approaches. Thus, none of the three EPA label approaches stands out with respect to their ability to predict relative onroad fuel economy as measured by AAA.

The AAA fuel economy values include two hybrids, a Prius and an Insight. Based on the official EPA label values, the AAA estimates were 6.6% lower than the current EPA composite fuel economy values for these two vehicles, 5% lower than for the average vehicle. Thus, the current label adjustments are indicating greater fuel economy improvement due to hybrid technology than AAA is finding during their testing.

In contrast, the AAA estimates average 10.6% and 12.0% higher than the mpg-based and 5-cycle combined fuel economy values for these two vehicles, respectively. These differences are about 6% and 4% greater difference than for the average vehicle, respectively. Thus, the 5-cycle and mpg-based formulae are indicating less fuel economy improvement due to hybrid technology than AAA is finding during their testing. Thus, the AAA testing is finding hybrid-related benefits somewhere in between those indicated by the current label formulae and those indicated by the mpg-based and 5-cycle formulae. This is in contrast to the Consumer Reports estimates, where their testing indicated hybrid benefits more consistent with those indicated by the 5-cycle formulae.

The consistency between the mpg-based equations and 5-cycle formulae with respect to the AAA hybrid testing is due to the fact that AAA only tested the two hybrids with the highest fuel economy label values. In this range of fuel economy, both the 5-cycle formulae and the mpg-based equations predict very similar values for hybrids. Consumer Reports, on the other hand, tested four hybrids, two of which have much lower fuel economy values. In this range, the mpg-based equations are dominated by conventional vehicles and the 5-cycle values for hybrids tend to fall below the mpg-based lines.

The main reason for the difference, however, is that AAA found much higher fuel economy values for the two hybrids which both organizations tested than Consumer Reports. Consumer Reports found that a 2000 Insight and 2004 Prius achieved combined fuel economy values of 51 mpg and 41 mpg, respectively. AAA found that a 2004 Insight and 2004 Prius achieved combined fuel economy values of 58 mpg and 52 mpg, respectively. In terms of fuel consumption, AAA found 17% less fuel use for these two hybrids than that found by Consumer Reports. We developed an analogous estimate for conventional vehicles by comparing the difference in fuel economy found by each organization for all the vehicles tested relative to the current and mpg-based label formulae. For conventional vehicles, in terms of fuel consumption, AAA found 8% less fuel use for these two hybrids than that found by Consumer Reports (. Thus, the different test procedures used by the two organizations are finding much different benefits of hybrid technology relative to conventional vehicles. This reinforces the observation that the capability of hybrid technology is sensitive to how and where the vehicles are operated (e.g., colder temperatures, trip length, driving pattern, etc.). The comparison of the fuel economy values predicted by the various label approaches to the onroad fuel economy estimated by Consumer Reports, AAA and other organizations is investigated further in Section II.D. below.

As part of their comments on the rule, AAA provided onroad and dynamometer fuel economy estimates for 42 additional vehicles. The average fuel economy recorded by the owners was 25.6 mpg, while the average of the current combined EPA label values was 29.6 mpg, Thus, this additional data indicates a 15% shortfall in onroad fuel economy relative to the current EPA label values. In addition, AAA tested 17 of these vehicles over the FTP, HFET, a hot start US06 and a US06 test with a cold start. On average, current EPA label values based the AAA FTP and HFET testing was very consistent with those implied by the vehicle labels. The average of the vehicles' combined city/highway label values (26.9 mpg) and those based on the AAA testing (26.8 mpg) differed by only 0.1 mpg. The average onroad fuel economy of these vehicles as estimated by the owners was 23.5 mpg. This indicated an onroad fuel economy shortfall of 12%, or slightly smaller than that for the complete set of 41 vehicles. The average cold start and hot start US06 fuel economy values for these vehicles were 23.1 and 25.0 mpg, respectively, bracketing the owners' experience. In contrast, the owner's fuel economy was lower than either the current city or highway label values for these 17 vehicles. AAA commented that the US06 test appeared to be a better predictor of onroad fuel economy than either the current city or highway label values and encouraged EPA to move forward with its proposed 5-cycle formulae, which included fuel economy measured over the US06 test.

3. Edmunds

The on-line car journal Edmunds.com measures fuel economy on new cars they evaluate for reviews. Edmunds reviews and road tests cars in a variety of ways, but the most relevant data come from their "long-term tests." For these tests they purchase or lease vehicles directly from dealers and keep the vehicle for 1-2 years, generally accumulating as much as 30,000 miles of experience with the vehicles from several different reviewers. Edmunds reports the best, worst, and average fuel economy achieved during their long-term use of the vehicle. We reviewed Edmunds data from 40 model year 2003-2006 long-term test vehicles and compared their average to the EPA "combined" city/highway fuel economy value. On average, the Edmunds reviewers achieved fuel economy about 14% lower than the current EPA combined label value. Hybrid vehicles performed even more poorly; the four included in the recent Edmunds long-term tests on average fell 24% below the current EPA combined label value. The data from Edmunds and current EPA City, Highway, and Combined label values are shown in Table II.B-5 below. As can be seen in this table, the average fuel economy achieved by Edmunds reviewers is frequently lower than the current EPA City estimate – in fact this occurs in more than half of the vehicles. And only in a minority of cases (8) does the best achieved by Edmunds exceed the EPA highway estimate, supporting the belief of many that the current highway fuel economy label value is a near best-case estimate.

Table II.B-5. 2003-2006 Edmunds Long-term Test Vehicles

			Edmunds.com (mpg)			Current EPA Label (mpg)		
MY	MFR	Model	Best	Worst	Avg.	City	Hwy	Combined
2006	Honda	Ridgeline	16.1	14.3	14.9	16.0	21.0	17.9
2006	Lexus	RX 400h	27.9	22.6	25.4	31.0	27.0	29.1
2006	Mitsubishi	Eclipse GT	19.2	14.6	16.5	18.0	27.0	21.2
2006	VW	Jetta	21.0	15.0	17.7	22.0	30.0	25.0
2005	Audi	A4 2.0T	27.7	16.2	22.3	22.0	30.0	25.0
2005	BMW	X3	21.6	16.9	17.2	16.0	23.0	18.5
2005	Chevrolet	Cobalt	27.3	20.2	24.9	24.0	32.0	27.0
2005	Dodge	Magnum	24.4	11.8	17.3	17.0	25.0	19.9
2005	Ford	Escape Hybrid	29.9	19.0	23.0	36.0	31.0	33.6
2005	Ford	GT	17.5	14.8	16.0	13.0	21.0	15.7
2005	Ford	Mustang GT	17.8	13.0	16.5	17.0	25.0	19.9
2005	Honda	Accord Hybrid	35.0	14.9	23.4	29.0	37.0	32.1
2005	Honda	Odyssey	22.7	15.3	18.5	20.0	28.0	23.0
2005	Kia	Spectra	28.9	17.5	23.6	25.0	34.0	28.4
2005	Landrover	LR3	27.6	12.6	16.3	14.0	18.0	15.6
2005	Nissan	Frontier 4x4 Nismo	18.2	12.7	14.6	15.0	20.0	16.9
2005	Scion	tC	31.6	14.7	21.6	22.0	29.0	24.7
2005	Subaru	Legacy GT	25.2	15.4	20.3	19.0	25.0	21.3
2005	Toyota	Solara	21.4	14.3	18.3	20.0	29.0	23.2
2005	Volvo	S40	25.3	19.6	22.4	20.0	27.0	22.6
2004	Acura	TL	25.2	18.1	22.8	20.0	28.0	23.0
2004	Chevrolet	Malibu	30.8	16.8	22.6	23.0	32.0	26.3
2004	Chrysler	Pacifica	20.7	9.9	15.8	17.0	22.0	18.9
2004	Ford	F-150	17.7	9.9	13.3	14.0	18.0	15.6
2004	GMC	Canyon	21.1	13.7	17.3	18.0	23.0	20.0
2004	Mazda	RX-8	22.5	12.0	17.5	18.0	24.0	20.3
2004	Mitsubishi	Endeavor	25.0	9.0	16.9	17.0	21.0	18.6
2004	Nissan	Quest	22.9	11.7	17.8	19.0	26.0	21.6
2004	Nissan	Titan	15.7	10.7	13.4	14.0	18.0	15.6
2004	Toyota	Prius	45.2	31.4	41.0	60.0	51.0	55.6
2004	Toyota	Sienna	19.1	12.5	15.7	19.0	27.0	21.9
2004	Volvo	XC90	19.6	15.1	17.7	15.0	20.0	16.9
2003	Honda	Accord	30.0	14.5	24.1	24.0	33.0	27.4
2003	Honda	Pilot EX	25.6	12.6	18.3	17.0	22.0	18.9
2003	Infiniti	G35 Coupe	23.2	13.1	15.4	20.0	27.0	22.6
2003	Lexus	SC 430	18.3	15.4	15.9	18.0	23.0	20.0
2003	Mazda	Mazda6	26.4	14.6	21.5	20.0	27.0	22.6
2003	Mitsubishi	Outlander	26.8	13.8	19.5	20.0	25.0	22.0
2003	Nissan	350Z	25.7	13.1	19.0	20.0	26.0	22.3
2003	Subaru	Forester	27.7	15.0	21.6	21.0	26.0	23.0

Table II.B-6 illustrates the differences between the Edmunds average values and the current EPA label, the MPG-specific values, and, for the hybrids, the 5-cycle values.

Table II.B-6. Edmunds Long-term Test Vehicles Compared to EPA Combined MPG Estimates

			Edmunds	EPA Combined Label (mpg)			Difference: Edmunds Vs. EPA (%)		
MY	MFR	Model	Avg.	Current	MPG-Based	5-Cycle	Current	MPG-Based	5-Cycle
2006	Honda	Ridgeline	15	18	16		-17%	-9%	
2006	Lexus	RX 400h	25	29	25	26	-13%	1%	-1%
2006	Mitsubishi	Eclipse GT	17	21	20	20	-22%	-16%	-19%
2006	VW	Jetta	18	25	23	24	-29%	-22%	-28%
2005	Audi	A4 2.0T	22	25	23		-11%	-2%	
2005	BMW	X3	17	19	17		-7%	0%	
2005	Chevrolet	Cobalt	25	27	25	25	-8%	1%	-2%
2005	Dodge	Magnum	17	20	18		-13%	-6%	
2005	Ford	Escape Hybrid	23	34	29	27	-31%	-20%	-15%
2005	Ford	GT	16	16	15	15	2%	8%	4%
2005	Ford	Mustang GT	17	20	18	19	-17%	-10%	-12%
2005	Honda	Accord Hybrid	23	32	29	26	-27%	-19%	-10%
2005	Honda	Odyssey	19	23	21	20	-19%	-12%	-9%
2005	Kia	Spectra	24	28	26	26	-17%	-9%	-8%
2005	Landrover	LR3	16	16	14		5%	14%	
2005	Nissan	Frontier 4x4 Nismo	15	17	16	15	-14%	-6%	-6%
2005	Scion	tC	22	25	22	24	-12%	-4%	-8%
2005	Subaru	Legacy GT	20	21	19	19	-5%	4%	7%
2005	Toyota	Solara	18	23	21		-21%	-15%	
2005	Volvo	S40	22	23	21	22	-1%	8%	1%
2004	Acura	TL	23	23	21	23	-1%	8%	0%
2004	Chevrolet	Malibu	23	26	24	24	-14%	-6%	-6%
2004	Chrysler	Pacifica	16	19	17		-17%	-9%	
2004	Ford	F-150	13	16	14	13	-15%	-7%	1%
2004	GMC	Canyon	17	20	18		-13%	-5%	
2004	Mazda	RX-8	18	20	19	19	-14%	-6%	-7%
2004	Mitsubishi	Endeavor	17	19	17	17	-9%	0%	-3%
2004	Nissan	Quest	18	22	20	19	-18%	-10%	-9%
2004	Nissan	Titan	13	16	14		-14%	-6%	
2004	Toyota	Prius	41	56	46	47	-26%	-12%	-12%
2004	Toyota	Sienna	16	22	20	20	-28%	-22%	-22%
2004	Volvo	XC90	18	17	16	16	5%	14%	7%
2003	Honda	Accord	24	27	25	26	-12%	-4%	-7%
2003	Honda	Pilot EX	18	19	18	18	-3%	3%	4%
2003	Infiniti	G35 Coupe	15	23	21	22	-32%	-27%	-29%
2003	Lexus	SC 430	16	20	19	19	-21%	-15%	-18%
2003	Mazda	Mazda6	22	23	21	22	-5%	3%	-2%
2003	Mitsubishi	Outlander	20	22	20		-11%	-5%	
2003	Nissan	350Z	19	22	21	22	-15%	-8%	-13%
2003	Subaru	Forester	22	23	21		-6%	1%	
		Average	19	23	21		-14%	-6%	-8%

As can be seen from Table II.B-6, both the mpg-based and 5-cycle formulae still produce fuel economy label values higher than those developed by Edmunds. However, the differences are smaller than with the current label formulae. The difference for the mpg-based equations is 8%, while that for the 5-cycle formulae is 7% (the Edmunds estimates being the lower of the two in both cases). While not shown, the standard deviation of the percentage difference is 12% for the mpg-based equations and 9% for the 5-cycle formulae. Thus, the relative differences in vehicles' fuel economy are slightly better indicated by the 5-cycle formulae.

The vehicles which Edmunds tested include four hybrids. The Edmunds fuel economy measurements are on average 24%, 13%, and 9% lower than the current, mpg-based and 5-cycle fuel economy label values, respectively. These percentage differences are 5-6% higher than those for the 40 vehicles tested on average for the current and mpg-based labels, but only 2% higher than that for the 5-cycle approach. Thus, the current and mpg-based approaches are indicating hybrid-related benefits which the Edmunds testing is not confirming. However, the relative benefit of hybrid technology as indicated by Edmunds testing and the 5-cycle approach are very similar. In this sense, the Edmunds testing is more consistent with that of Consumer Reports, versus AAA.

In contrast, the current, mpg-based and 5-cycle fuel economy label values for the 10% conventional vehicles with the highest fuel economy average 18%, 8%, and 8%, respectively. These latter differences are very similar to those for the average conventional vehicle. The same findings hold for the 20% of conventional vehicles with the highest fuel economy. Thus, the Edmunds testing is finding something about hybrids which is not occurring with either typical or high fuel economy conventional vehicles.

C. Fleet-wide Estimates of Onroad Fuel Economy

We begin with a comparison of the 5-cycle fuel economy values with the fleetwide fuel economy estimates developed by FHWA. Because we do not have fuel economy data for all vehicles over all 5 dynamometer cycles, and therefore cannot develop a 5-cycle fuel economy estimate for the current onroad fleet directly, this comparison requires a two step process.

The first step in this process compares fleetwide fuel economy estimates based on EPA's current fuel economy labels to the FHWA estimate of onroad fuel economy. The second step in this process is to compare combined city-highway fuel economy using the 5-cycle formulae to that using the current EPA city and highway label procedures. This comparison is performed for vehicles for which we have 5-cycle fuel economy data. We will assume that this relationship also applies to those vehicles for which we do not have 5-cycle data.

In the NPRM, we added a third step which evaluated changes in FTP and HFET test procedures which accompanied the implementation of the US06 and SC03 testing requirements. We estimated that these changes had a positive impact on the fuel economy values measured during these tests. However, as discussed in the Response to Comments document, we now believe that these changes had a neutral impact on fuel economy. Thus, this third step is no longer needed.

Overall, the difference between 5-cycle fuel economy and FHWA onroad fuel economy is the combination of the percentage differences from the two comparisons:

1) Current EPA label fuel economy to FHWA onroad fuel economy, and
2) 5-cycle fuel economy to current EPA label fuel economy (without 10% road load adjustment).

FHWA publishes fleet-wide estimates of onroad fuel economy for cars and light trucks in their annual Highway Statistics publication.[4] We will focus on the combined estimates for cars and light trucks here, since various states use different criteria to distinguish between the two vehicle classes. At the same time, the criteria used to distinguish between cars plus light trucks and other vehicles are very consistent.

Table II.C-1 presents the FHWA estimates of vehicle miles traveled (VMT), fuel consumption and onroad fuel economy for passenger cars and 4-tire, 2-wheel trucks.

Table II.C-1. FHWA-Based Estimate of Onroad Fuel Economy

	Year	2003	2004
Passenger cars	VMT (million miles)	1,672,079	1,704,982
	Fuel Use (thousand gallons)	75,455	76,007
	MPG (mpg)	22.2	22.4
2 axle 4 tire Trucks	VMT (million miles)	984,094	1,014,342
	Fuel Use (thousand gallons)	60,758	62,626
	MPG (mpg)	16.2	16.2
Light trucks	VMT (million miles)	908,712	936,643
	Fuel Use (thousand gallons)	55,271	56,970
	MPG (mpg)	16.4	16.4
Passenger cars and light trucks	VMT (million miles)	2,580,791	2,641,625
	Fuel Use (thousand gallons)	130,726	132,976
	MPG (mpg)	19.7	19.9

The FHWA category of 4-tire, 2-wheel trucks includes some vehicles which EPA classifies as heavy-duty vehicles. We have adjusted the FHWA estimates upward to provide a more direct comparison. This adjustment is based on a study performed by Oak Ridge National Laboratory (ORNL).[5] ORNL estimated both VMT and fuel use for several categories of light trucks. Class 1 and 2a trucks fall into EPA's definition of light-duty trucks, while Class 2b trucks do not. Together, the three classes of trucks are approximately equivalent to FHWA's 4-wheel, 2-axle truck class. The results of this study are shown in Table II.C-2.

Table II.C-2. Breakdown of VMT and Fuel Use by 4-Wheel, 2-Axle

	VMT (billions)	Fuel use (billion gallons)
Class 1	672.7	37.4
Class 2a	251.9	18
Class 2b	76.7	5.5
Total	1,001	60.9
Class 1+2a	92.3%	91.0%

As can be seen, ORNL estimated that 92.3% of the VMT and 91.0% of the fuel use by 4-wheel, 2-axle trucks was by vehicles falling into EPA's light-duty truck category (and which are labeled for fuel economy). Therefore, we adjusted FHWA's VMT and fuel use estimates for 4-wheel, 2-axle trucks by these percentages to convert them to values applicable to EPA's light-duty truck class. These adjusted values and the resulting onroad fuel economy are shown in Table II.C-1. We then added the VMT and fuel use by passenger cars and EPA light trucks together and calculated an overall fuel economy for the two vehicle classes. These values are also shown at the bottom of Table II.C-1. The result is that the FHWA-based estimate of fleet-wide onroad fuel economy for cars and EPA light trucks is 16.4 mpg for 2003 and 2004. This is nearly 20% lower than the onroad fuel economy for light trucks presented in the NPRM analysis. The difference is due to the use of more recent figures from FHWA which considers fuel economy data indicating lower fuel economy from light trucks than previously estimated.

We then used the EPA MOBILE6.2 in-use emission model to calculate fleet-wide average EPA combined fuel economy label values for these two years. MOBILE6.2 estimates fuel economy using a sales-weighted average of the combined EPA city/highway label values for each model year of cars and light trucks. MOBILE6.2 then estimates an average fuel economy for the onroad fleet by weighting the fuel economy values for each model year by the fraction of vehicles on the road from each model and their typical annual mileage (which decreases with age). Thus, MOBILE6.2 is an ideal tool for estimating the EPA label fuel economy using the current label formulae for the onroad vehicle fleet in any particular calendar year.

For 2003, MOBILE6.2 estimates average passenger car and light truck fuel economy of 24.0 mpg and 17.3 mpg, respectively. For 2004, MOBILE6.2 estimates average passenger car and light truck fuel economy of 24.0 mpg and 17.4 mpg, respectively. We weighted the fuel economy values for cars and light trucks together using their respective VMT from Table II.C-1. The result were overall average label fuel economy values of 21.1 mpg for 2003 and 21.2 mpg for 2004. Thus, for 2003 and 2004, the FHWA-based onroad fuel economy was 6.5% and 6.1% lower than the current combined EPA label value, respectively. Thus, the result of the first step in this process is an indication that the current labeling formulae could be over-estimating onroad fuel economy by 6-7%.

Moving to the second step, in Tables III.E-1 and III.E-2 shown in Section III.E below, we present city and highway fuel economy label values using both current and 5-cycle formulae for 615 2003-2006 model year vehicles. The FHWA estimates apply to all driving, both city and highway. Therefore, we are primarily interested in combined city-highway fuel economy values. Also, we are using FHWA estimates for the 2003 and 2004 calendar years, as these are the most recent available. The number of hybrid vehicles on the road was very low during this timeframe, much lower than the 2% level present in our certification database. Therefore, we will only use the 5-cycle fuel economy estimates for the 601 non-hybrid vehicles in our database. There is no need to perform this comparison separately for the mpg-based formulae, since the average fuel economy from the 5-cycle and mpg-based formulae are identical for non-hybrid vehicles.

The combined fuel economy using the current label formulae is a 55/45 harmonic weighting of the current city and highway fuel economy labels. The average combined fuel economy using the current EPA label values for these 601 vehicles is 20.9 mpg. For the final 5-cycle formulae, combined fuel economy is a 43/57 harmonic weighting of the 5-cycle city and highway fuel economies. This city/highway split for the 5-cycle fuel economies is based on:

1) the assumption that driving generally less than 45 mph is city driving and that above 45 mph is highway driving, and

2) the description of onroad driving patterns contained in MOVES.

The mathematical formula for converting the 5-cycle city and highway fuel economy values into an estimate of average onroad fuel economy is as follows:

$$Average\,onroad\ \ fuel\,economy = \frac{1}{\left(\dfrac{0.43}{5 - cycle\,City\,FE}\right) + \left(\dfrac{0.57}{5 - cycle\,Highway\,FE}\right)}$$

The average combined 5-cycle fuel economy using this formula for the 601 conventional vehicles is 19.6 mpg, which is 6.2% lower than that based on the current label values. This is the result of the second step in the process.

Overall, then, the current label values over-estimate onroad fuel economy per FHWA (with some adjustments by EPA) by 6-6.5%, while the 5-cycle formulae decrease current label values (of the 2002-2003 fleet) by 6.2%. Thus, the final 5-cycle formulae should move the combined fuel economy label values to within a few tenths of a percent of a comparable estimate of fleetwide fuel economy using FHWA techniques. This should not be surprising, since the value of the factor in the 5-cycle formulae representing factors not represented in dynamometer tests was set to match onroad fuel economy as estimated by FHWA (see Section III.A.5 below).

D. Overall Comparison of Hybrid Fuel Economy

When comparing onroad fuel economy to EPA estimates, it is often appropriate to focus on the EPA combined fuel economy, as it is not possible to determine whether a particular vehicle’s driving was city-like or highway-like. Overall, the 5-cycle formulae predict a combined fuel economy about 6% less than the current combined fuel economy label for our 615 vehicle certification fuel economy database.

These relationships hold for the complete 615 vehicle database, as well as the 601 conventional vehicles which dominate the database. However, the effect of the 5-cycle formulae on the combined fuel economy of hybrids is much more significant. Overall, the 5-cycle formulae predict a combined fuel economy about 18% less than the current combined fuel economy label for the 14 hybrids in our certification fuel economy database. Thus, the 5-cycle formulae reduce hybrid fuel economy roughly 12% more than non-hybrids compared to today's labels. Two thirds of this difference occurs in city fuel economy. It is primarily due to a greater impact of running fuel use at colder temperatures and inclusion of US06 city driving in the 5-cycle formulae. This difference appears to be related more to hybrid technology itself, as opposed to just high fuel economy values. For example, the average impact of the 5-cycle formulae on the combined fuel economy of the top 10% of conventional vehicles in terms of current combined fuel economy is 8%. This is only 2% greater than that for all conventional vehicles and well below that for hybrids.

Some care must be taken in relating to this difference between the impact of the 5-cycle formulae on conventional and hybrid vehicles. First and foremost, the impact of the 5-cycle formulae on label fuel economy involves a number of projections which may not be accurate for individual vehicles. For example, we currently lack measured fuel economy values over the US06 city and highway bags. Thus, these must be estimated. We are using one relationship for conventional vehicles and another relationship for hybrids. The former is based on the testing of over 100 vehicles, which shows fairly consistent results. The latter is based on the testing of two vehicles. The relative performance of other hybrid vehicles over the two bags of the US06 test could differ significantly from our current estimate. Similarly, we have included the effect of turning on the heater or defroster during the cold FTP, as this will be required in the future. However, the data currently available on fuel economy over the cold FTP do not include this factor. Our projected impact for conventional vehicles is relatively small. Thus, variability between vehicles is likely even smaller. However, the testing of two hybrids showed large impacts on Bag 1 fuel economy at 20°F. Other hybrids may show different impacts.

Second, manufacturers may improve their hybrid designs in the future to reduce the impact of colder temperatures, air conditioning operation, etc. While we believe that manufacturers have always been concerned about fuel efficiency under realistic conditions, the fact that fuel economy labels have been based solely on operation at 75°F has inevitably focused their attention especially on this type of operation. Hybrid technology is still relatively new and improvements are constantly being made. With the 5-cycle formulae, we expect that these improvements will affect vehicle operation over a much wider set of in-use conditions than might have been the case with the current label formulae.

Nonetheless, the question still arises: is this greater reduction in combined fuel economy of today's hybrids appropriate? In this section, we compile all the onroad fuel economy measurements and consumer organization estimates in one place and compare them to combined fuel economy estimated using the current, 5-cycle and mpg-based formulae.

Table II.D-1 compares three sets of onroad fuel economy measurements to both current and final EPA combined fuel economy label values. Combined fuel economy using the current label formulae weights city fuel economy 55% and highway fuel economy 45%. Combined fuel economy using the 5-cycle and mpg-based label formulae weighs city fuel economy by 43% and highway fuel economy by 57%. It should be noted that the values for current combined fuel economy are those from EPA's certification database in order to be directly comparable to the 5-cycle and mpg-based values. However, they are not the current official label values. The official label values average about 3% higher due to differences between the worse case vehicles tested over the Supplemental FTP cycles and the average vehicle sold.

Table II.D-1. Onroad Hybrid Fuel Economy Versus EPA Label Estimates (mpg)

	EPA Combined Fuel Economy			Onroad Fuel Economy Measurements		
	Current	MPG-Based	5-Cycle	DOE FreedomCar	YourMPG	EPA Kansas City
2001 Honda Insight	61	51	50	45	66	47
2003 Honda Civic	46	40	37-38	38	46	40
2004 Toyota Prius	54	45	45	45	48	50
2004 Chevrolet Silverado 4wd	16	15	15	18	15	---
2005 Ford Escape 4wd	30	26	24	27	30	---
2005 Honda Accord	32	29	26	28	31	---
2005 Lexus RX400h	28	24	24	25	25	---

It is difficult to draw any definite conclusions from the above data due to its scatter. The onroad fuel economy estimates from the YourMPG database tend to be significantly higher than those from the DOE FreedomCar project. The Kansas City measurements tend to fall in between, except for the Prius. Label fuel economy values based on all three approaches can come close to one of the three onroad fuel economy estimates, even for the same vehicle.

For example, the current EPA label formulae appear to significantly over-estimate fuel economy as measured in the FreedomCar program, except for the Chevrolet Silverado. This vehicle has the least hybrid capability with respect to improved fuel economy of the vehicles listed in Table II-D.1. The mpg-based and 5-cycle label formulae tend to perform equally well with respect to the DOE FreedomCar program

In contrast, the current label formulae provide reasonable estimates of onroad fuel economy for five of the seven hybrids based on the YourMPG database. The mpg-based and 5-cycle label formulae do so for four of the seven hybrids based on the YourMPG database. As would be expected, the sets of five and four hybrids tend not to overlap.

Finally, the current label formulae over-estimate onroad fuel economy as measured in the Kansas City test program. The mpg-based and 5-cycle label formulae tend to provide reasonable estimates of onroad fuel economy as measured in Kansas City on average, over-estimating fuel economy for one of the three matched hybrids and under-estimating fuel economy for one hybrid.

Table II.D-2 compares onroad fuel economy estimates by consumer organizations to EPA estimates.

Table II.D-2. Onroad Hybrid Fuel Economy Estimates Versus EPA Label Estimates (mpg)

	EPA Combined Fuel Economy			Onroad Fuel Economy Estimates		
	Current	MPG-Based	5-Cycle	Consumer Reports	Edmunds	AAA
2001 Honda Insight	61	51	50	51	---	58
2003 Honda Civic	46	40	37-38	36	---	---
2004 Toyota Prius	54	45	45	44	41	52
2005 Ford Escape 4wd	30	26	24	26	23	---
2005 Honda Accord	32	29	26	25	23.4	---
2005 Lexus RX400h	28	24	24	---	25.4	---

Again, there is significant scatter in the data. Of the three consumer organizations, Edmunds predicts the lowest fuel economy. The Edmunds fuel economy values are lower than all three sets of EPA fuel economy estimates. Since the 5-cycle formulae produce the lowest estimates on label fuel economy, the 5-cycle formulae come closest to matching the Edmunds' fuel economy values.

The 5-cycle fuel economy values match those of Consumer Reports very closely, differing by at most 2 mpg for any individual vehicle. The mpg-based estimates are higher for three of the five matching hybrids. The current label values exceed those found by Consumer Reports significantly in all cases.

The two AAA estimates are higher than the 5-cycle and mpg-based estimates, but lower than (but closer to) the current EPA estimates. Overall, the 5-cycle formulae tend to match the findings of the three consumer organizations more closely than the other two label approaches. However, there is significant scatter in the data. Over time, we will continue to assess how our 5-cycle estimates compare with those of other studies. In particular, it would be useful to have both vehicle activity and fuel economy data, coupled with environmental conditions in order to more precisely verify the ability of the five cycles to estimate onroad fuel economy under the full range of ambient conditions.

Chapter II References

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4. U.S. Department of Transportation, Federal Highway Administration. Highway Statistics 2004. See Table VM-1. Website: http://www.fhwa.dot.gov/policy/ohim/hs04/htm/vm1.htm.

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Chapter III: Documentation of Final Approach for Estimating On-Road Fuel Economy

The current fuel economy label values utilize measured fuel economy over city (FTP) and highway (HFET) driving cycles and adjust these values downward by 10 and 22%, respectively, to account for a variety of factors not addressed in EPA's vehicle test procedures. These factors include differences between the way vehicles are driven on the road and over the test cycles, air conditioning use, widely varying ambient temperature and humidity, widely varying trip lengths, wind, precipitation, rough road conditions, hills, etc.

The purpose of the new formulae for city and highway fuel economies is to better account for three of these factors: 1) on-road driving patterns (i.e., vehicle speeds and accelerations), 2) air conditioning, and 3) colder temperatures. Vehicles are often driven more aggressively and at higher speeds than is represented in the FTP and HFET tests, which have maximum speeds of 55-60 mph and maximum acceleration rates of 3.2-3.3 mph per second. The incorporation of measured fuel economy over the US06 test cycle into the fuel economy label values makes the label values more realistic, as this cycle includes speeds up to 80 mph and acceleration rates of 8.4 mph per second.

Drivers often use air conditioning in warm, humid conditions, while the air conditioner is turned off during the FTP and HFET tests. The incorporation of measured fuel economy over the SC03 test cycle into the fuel economy label values reflects the added fuel needed to operate the air conditioning system. The SC03 test is performed at 95 degrees Fahrenheit (^{o}F) with simulated solar heating.

Vehicles are also often driven at temperatures below 75^{o}F, at which the FTP and HFET tests are performed. The incorporation of measured fuel economy over the cold temperature FTP test into the fuel economy label values reflects the additional fuel needed to start up a cold engine at colder temperatures.

We developed two methods for incorporating these three factors into our onroad fuel economy predictions. The first method, termed vehicle specific 5-cycle, combines the fuel economy over all five dynamometer cycles in a vehicle specific manner (i.e., as much information as possible reflects the fuel economy performance of the specific vehicle being examined). The second method, termed mpg-based, utilizes fuel economy estimates based on the vehicle specific 5-cycle method for a large number of vehicles and develops generic adjustment factors as a function of the vehicle's FTP and HFET fuel economy values.

In Section III.A, we describe the development of the vehicle specific 5-cycle method. In Section III.B, we describe the mpg-based method. In Section III.C, we evaluate the range and variability of onroad fuel economy experienced by drivers of the same vehicle. In section III.D, we describe how the current city and highway fuel economy values would change under the two final methods. Finally, in section III.E, we evaluate the sensitivities and uncertainties in the vehicle specific 5-cycle formulae.

A. Vehicle Specific 5-Cycle Method for Estimating On-Road Fuel Economy from Dynamometer Tests

The city and highway fuel economy label values are intended to give the vehicle purchaser an idea of the fuel economy that they should expect to achieve while driving the vehicle during normal use. As such, the label values are intended to take into account the effect of seasonal and geographical variations on automotive fuel economy, as well as the different driving habits of individual drivers. Due to variations in climate and the way various drivers drive their vehicle, no one set of fuel economy values can accurately predict any individual drivers' actual fuel economy while driving. However, the set of fuel economy values should be able to predict on-road fuel economy for the average driver under average environmental conditions. The goal of the analysis presented below is to use the available fuel economy information developed during emission and fuel economy testing to predict on-road fuel economy under these "average" conditions to the greatest extent possible. This onroad average fuel economy can then be adjusted to represent more worse-case conditions, such as 25th or 10th percentile estimates (i.e., fuel economy levels achieved by 75% or 90% of all drivers, respectively), which is discussed in Section III.C below.

As described in the preamble to this final rule, we chose to base the fuel economy label values on vehicle emission and fuel economy tests which are already being performed. This minimizes the costs associated with the final rule, as described below in Chapter IV. The five current emission and fuel economy tests and their key aspects are described below in Table III.A-1.

Table III.A-1. Key Features of the Five Current Emission and Fuel Economy Tests

Test	Driving	Ambient Temperature	Engine Condition at Start	Accessories
FTP	**Low speed**	75°F	**Cold** and hot	None
HFET	**Mid-speed**	75°F	Hot	None
US06	**Aggressive; low and high speed**	75°F	Hot	None
SC03	Low speed	**95°F**	Hot	**A/C on**
Cold FTP	Low speed	**20°F**	**Cold** and hot	None

We have highlighted in bold the distinctive features of the five current vehicle tests. The FTP, HFET and US06 are all performed at an ambient temperature of 75°F. Each test consists of a distinctive driving pattern. In addition, the FTP test consists of three distinct measurements, called bags because the emissions produced during each portion of the test are literally collected in separate plastic "bags". Bags 1 and 3 consist of the exact same driving pattern, while Bag 2 consists of a different pattern. Thus, fuel economy measurements at 75°F are available for four distinct driving cycles.

Bag 1 begins with an engine start after the vehicle has been sitting with the engine off for at least 12 hours, representing an overnight soak (soak refers to the time during which a vehicle sits with its engine off). This is referred to as a "cold" start. In this case, the cold start occurs at

75°F, which may not seem not very "cold". However, the engine is at the same temperature as the ambient air, so it is referred to as being "cold". After sitting this long, the engine has essentially fully cooled off and sitting longer has no effect on either emissions or fuel economy. Bag 3 begins with an engine start after the vehicle has been sitting with the engine off for only 10 minutes, representing a short stop to refuel, a short shopping trip, etc. This is referred to as a "hot" start, since the engine is still essentially at its fully warmed up temperature. In-use, vehicle soaks between starts occur anywhere between a few seconds to a few days. The hot and cold starts are intended to bracket this distribution of in-use soak times and ensure that vehicle manufacturers design their emission control systems to work efficiently under a wide range of operation. Practically speaking, very little fuel is necessary to warm up the vehicle after it has been sitting with the engine off for only 10 minutes. Thus, the difference between fuel use over Bags 1 and 3 is that associated with a cold start. As indicated in Table III.A-1, this estimate is available at both 75 and 20°F.

The SC03 test is the only test performed with the air conditioning system operational. Therefore, its results are used to augment the fuel economy from the five driving pattern tests for the fuel needed to operate air conditioning. The cold FTP is the only test performed at a temperature below 75°F. Therefore, its results are used to represent the additional fuel needed to warm up an engine after a cold start, as well as any fuel needed to operate a warmed up engine, at colder temperatures.

Conceptually, our approach to modeling fuel economy can be depicted as follows:

Onroad fuel economy =
Warmed up fuel economy (from Bags 2 and 3 of the FTP, HFET and US06 cycles),
decreased by the need to warm up a cold engine (from Bags 1 and 3 of the FTP and cold FTP),
decreased by use of the air conditioner (from SC03), and
decreased due to operation at colder temperatures (from the cold FTP).

Actually, since cold starts, air conditioning and colder temperatures simply add fuel use over and above that needed for warmed up driving, it is more straightforward to model these effects in terms of fuel consumption (e.g., gallons of fuel used per mile) than in terms of fuel economy. In terms of fuel consumption, the above equation looks like this:

Onroad fuel economy = 1/ Onroad fuel consumption

Onroad fuel consumption =
Warmed up fuel consumption (from Bags 2 and 3 of the FTP, HFET and US06 cycles),
plus the extra fuel associated with
1) warming up a cold engine (from Bags 1 and 3 of the FTP and the cold FTP),
2) use of the air conditioner (from SC03), and
3) operation at colder temperatures (from the cold FTP).

The remainder of this section is broken up into 6 pieces. The first, section III.A.1, develops a methodology for estimating fuel use related to engine start-up, or start fuel use. The second, Section III.A.2, develops a methodology for estimating fuel use once the engine is warmed up at 75°F, assuming that the air conditioner is not turned on. The third, Section III.A.3, develops a methodology for estimating fuel use due to air conditioner use. The fourth, Section III.A.4, develops a methodology for estimating fuel use once the engine is warmed up at colder temperatures. This fourth section also presents a combination of the results from the previous two sections into overall formulae for running fuel use during city, highway and composite driving. The fifth, Section III.A.5, evaluates the impact of factors that affect onroad fuel economy but which are not addressed by any of the five dynamometer cycles. The sixth, Section III.A.6, presents for final 5-cycle city and highway fuel economy formulae.

1. Start Fuel Use

We estimate the fuel needed to start and warm up the engine separately from fuel used to operate the engine after start-up, or running fuel use primarily to be able to estimate fuel economy for trips of various lengths. The longer the trip, the less significant is start fuel use. This is consistent with the approach taken in EPA emission models, such as MOBILE6.2 and MOVES. We estimate the volume of fuel needed to start and warm up an engine first. We then estimate average trip lengths for both city and highway driving. Finally, we combine the two estimates to develop a formula for start fuel use for typical trip lengths during city and highway driving.

a. Start Fuel

For a specific vehicle, the fuel needed to warm up the engine depends primarily on two factors:

1) The ambient temperature at which the vehicle has been sitting, and
2) The length of time that the vehicle has been sitting since it was last used (commonly referred to as soak time).

Emissions during engine start up have been studied for some time.[1] Most recently, estimates of start fuel use as a function of ambient temperature were made for use in EPA's new emission inventory model, MOVES (MOtor Vehicle Emission inventory System).[d] For MOVES, EPA analyzed start fuel use from 580 gasoline fueled vehicles.[2] In this analysis, the start fuel use measured was the difference between fuel use during Bag 1 of the FTP and Bag 3 of the FTP. The only difference between these two bags is the time prior to the test that the engine has been turned off, or "soaking." Prior to Bag 1, the engine has been off for 12 hours or more. This start is commonly referred to as a cold start. Prior to Bag 3, the engine has been off for only 10 minutes. This start is commonly referred to as a hot start. Since start fuel use during a hot start is much lower than that during a cold start, the difference between start fuel use for a cold start and a hot start is usually assumed to be that of the cold start.

The resulting relationship between cold start fuel use at other ambient temperatures relative to that at 75°F (a typical temperature for the standard FTP test) is as follows:

[d] A draft of MOVES2004 was released for public comment on Dec. 31, 2004.

Equation 1

$$Cold\ Start\ Fuel\ Use\ \mathrm{Re}lative\ to\ that\ at\ 75F =$$
$$1-(0.01971\times(AmbientTemperature-75))+(0.000219\times(AmbientTemperature-75)^2)$$

At 75°F, the nominal temperature of the FTP test, this formula yields a value of 1.0. At 20°F, for example, the temperature of the cold temperature FTP, it yields a value of 2.75. This means that the volume of fuel needed to start and warm up an engine and drivetrain is 2.75 times as great after a 12 hour soak at 20°F as it is at 75°F. These relationships assume that the vehicle had been sitting with the engine turned off for the same amount of time at each temperature.

It should be noted that none of the 580 vehicles tested incorporated hybrid technology. Thus, the application of Equation 1 to hybrids involves greater uncertainty than for other gasoline vehicles. This issue is addressed in detail in Section III.E below.

EPA also analyzed start fuel use for diesel vehicles. Relevant data were only available for 66 vehicles, or roughly one-tenth the number of gasoline vehicles. Based on these data, EPA found that start fuel use for diesels was roughly 44% that of gasoline vehicles. Thus, the relationship between cold start fuel use at other ambient temperatures relative to that at 75°F for diesels is as follows:

Equation 2

$$Diesel\ Cold\ Start\ Fuel\ Use\ \mathrm{Re}lative\ to\ that\ at\ 75F =$$
$$1-(0.00867\times(AmbientTemperature-75))+(0.000096\times(AmbientTemperature-75)^2)$$

For a typical diesel vehicle, start fuel use after a cold start at 20°F is only 1.77 times that at 75°F.

Moving to the issue of soak time prior to engine start up, the Draft MOVES2004 model does not yet include estimates for the effect of soak time on start fuel use. Therefore, we obtained a relationship between start fuel use and ambient temperature which was developed by the California Air Resources Board for use in their emission inventory model, EMFAC2000.[3] These relationships were based on the testing of 238 vehicles. EPA utilizes the results of this study in our current emission model, MOBILE6.2, to estimate the effect of soak time on regulated emissions (VOC, CO, NO_X) during start-up. The equation for fuel use versus soak time (in minutes) relative to the fuel use after a 12 hour soak is as follows:

For soaks of 90 minutes or less:

Equation 3

$$StartFuelUse_x = 0.00433672\times SoakTime-0.000002393\times SoakTime^2$$

For soaks greater than 90 minutes:

Equation 4

$$StartFuelUse_x = 0.25889542 + 0.0014848 \times SoakTime - 0.0000006364 \times SoakTime^2$$

As is done in EMFAC2000 and MOBILE6.2, we assumed that these relationships are independent of ambient temperature.

In order obtain the combined effect of ambient temperature and soak time, we combined the above equations multiplicatively, as follows:

For gasoline vehicles:

For soaks of 90 minutes or less:

Equation 5

$$StartFuelUse_x = \left[0.00433672 \times SoakTime - 0.000002393 \times SoakTime^2\right] \times \left[1 - 0.01971 \times (AmbientTemperature - 75) + 0.000219 \times (AmbientTemperature - 75)^2\right]$$

For soaks greater than 90 minutes:

Equation 6

$$StartFuelUse_x = \left[0.25889542 + 0.0014848 \times SoakTime - 0.0000006364 \times SoakTime^2\right] \times \left[1 - 0.01971 \times (AmbientTemperature - 75) + 0.000219 \times (AmbientTemperature - 75)^2\right]$$

For diesel vehicles:

For soaks of 90 minutes or less:

Equation 7

$$StartFuelUse_x = \left[0.00433672 \times SoakTime - 0.000002393 \times SoakTime^2\right] \times \left[1 - 0.00867 \times (AmbientTemperature - 75) + 0.000096 \times (AmbientTemperature - 75)^2\right]$$

For soaks greater than 90 minutes:

Equation 8

$$StartFuelUse_x = \left[0.25889542 + 0.0014848 \times SoakTime - 0.0000006364 \times SoakTime^2\right] \times \left[1 - 0.00867 \times (AmbientTemperature - 75) + 0.000096 \times (AmbientTemperature - 75)^2\right]$$

All of the above equations estimate start fuel use in terms of the fraction of start fuel use following an overnight soak at 75°F, which are the conditions of the "cold start" contained in the FTP. We will use these equations to estimate the relative start fuel use for the range of starting conditions occurring throughout the nation. We will then sum up these start fuel volumes and estimate the average start fuel use for an engine start in the U.S. Then, we will estimate the combination of start fuel volumes measured in the FTP tests performed at 20 and 75°F which is equal to the national average start fuel use.

The "hot" and "cold" starts contained in the standard and cold temperature FTP tests occur after 10 minute and 12 hour or longer hour soaks, respectively. With the hot start, the engine was fully warmed up prior to the test and turned off for 10 minutes prior to being turned on again at the start of the hot start portion of the FTP. With the cold start, the vehicle has been sitting with the engine off for at least 12 hours in a room at the temperature specified.

Equations 3 and 4 relating the effect of soak time on start fuel use indicate that the start fuel use after a 10 minute soak is only 4% of that after a 12 hour soak. Equation 1 relating the effect of temperature on start fuel use from gasoline vehicles indicates that start fuel use at 20°F is 2.75 times that at 75°F. Combining these effects, the start fuel use after a 10 minutes soak at 20°F is about 11% (0.04 * 2.75) of the start fuel use following a 12 hour soak at 75°F. Thus, the start fuel use after the hot starts of both standard and cold temperature FTP tests are relatively small compared to that of a cold start at 75°F. The US06, SC03 and HFET tests begin with a hot start at 75°F, as is the case with Bag 3 of the FTP. Hereafter, we ignore any start fuel use included in these three tests due to their hot start. (Bag 2 of the FTP does not begin with an engine start. The sampling equipment simply switches the emissions from Bag 1 to Bag 2 during a vehicle idle at second 505 of the test.)

In order to estimate start fuel use throughout the U.S. under average ambient conditions, we need estimates of the soak times for typical vehicle operation, as well as the ambient temperature at start up. The amount of time a vehicle has sat prior to start up varies dramatically depending on the time of day at which it is started. For example, for vehicles started up at 6 am, nearly all have sat overnight. However, for vehicles started at noon, most have been driven in the past 4-5 hours. Ambient temperatures vary significantly during the day, so it is more accurate to evaluate start fuel use by hour of the day rather than simply at the daily average temperature. Ambient temperatures also vary dramatically across the U.S., as does the distribution of vehicle miles traveled (VMT). Therefore, we combined estimates of vehicle starts and prior soak times by hour of the day with estimates of ambient temperature and VMT by county in order to reflect the effects of both soak time and ambient temperature on start fuel use.

We obtained estimates of each of these input parameters from EPA's MOBLE6.2 and MOVES2004 emission models. The Draft MOVES2004 model includes estimates of ambient temperature by hour of the day for each month of the year for each county in the U.S.[4] These estimates were obtained from the National Weather Service and represent 30-year averages. The Draft MOVES2004 model also includes estimates of vehicle miles traveled (VMT) by vehicle type for every county in the U.S. during 2002.[5] We assumed that the distribution of engine starts across counties was the same as that for VMT (i.e., that trip length was the same across the U.S.). We used these estimates to determine the percentage of total U.S. VMT by cars (LDVs) and light trucks (LDTs) occurring in each county (excluding Puerto Rico and the Virgin Islands).

MOBILE6.2 includes estimates of the frequency distributions of vehicle soak times prior to vehicle start-up by time of day, as well as the frequency distribution of vehicle starts by hour of the day.[6] Table III.A-2 presents the distribution of starts by the hour of the day. MOBILE6.2

includes separate estimates for weekdays and weekends. Since we are primarily concerned with fuel use on an annual average basis, we combined the two sets of estimates by weighting the percentage of vehicle starts occurring after specific lengths of soak at each hour of the day for weekdays by five-sevenths and those for weekends by two-sevenths and added the two sets of percentages. This is indicated below.

Table III.A-2. Distribution of Starts by Hour of the Day (in percent)

Hour of the Day	Weekday	Weekend	Average Day
6 am	2.04	0.91	1.72
7 am	5.54	1.93	4.51
8 am	6.02	3.10	5.19
9 am	4.73	6.45	5.22
10 am	5.16	6.91	5.66
11 am	6.72	7.97	7.08
Noon	8.07	10.16	8.67
1 pm	7.30	7.26	7.29
2 pm	8.04	8.89	8.28
3 pm	8.98	7.36	8.52
4 pm	8.41	8.02	8.30
5 pm	7.73	7.11	7.55
6 pm	6.02	6.15	6.05
7 pm - 5 am	15.24	17.78	15.97

The relative amounts of VMT by month of the year were taken from the Draft MOVE2004 model and are shown in Table III.A.-3 below.[7] MOVES includes estimates for both non leap years and leap years. We averaged the two estimates in a 3:1 ratio to develop estimates for a typical year.

Table III.A-3. Breakdown of Annual VMT by Month

Month	Non Leap Year	Leap Year	Average Year
January	0.0731	0.0729	0.0731
February	0.0697	0.0720	0.0703
March	0.0817	0.0815	0.0817
April	0.0823	0.0821	0.0823
May	0.0875	0.0873	0.0875
June	0.0883	0.0881	0.0883
July	0.0923	0.0921	0.0923
August	0.0934	0.0932	0.0934
September	0.0847	0.0845	0.0847
October	0.0865	0.0863	0.0865
November	0.0802	0.0800	0.0802
December	0.0802	0.0800	0.0802

We obtained our estimate of total VMT by LDVs and LDTs by county from that used in the Draft 2002 Mobile National Emission Inventory.[5] We assumed that trip length is independent of the season of the year.

We first estimated the effect of soak time on start fuel use by hour of the day. The first step in this procedure was to estimate the percentage of vehicle starts occurring after specific lengths of soak at each hour of the day. As is the case for vehicle starts by time of day, MOBILE6.2 includes estimates of soak times for weekdays and weekends. Again, we weighted the percentage of vehicle starts occurring after specific lengths of soak at each hour of the day for weekdays by five-sevenths and those for weekends by two-sevenths and added the two sets of percentages. MOBILE6.2 tracks 69 distinct intervals of soak time for 14 “hours” of the day (starts between 9 pm and 5:59 am are combined into a single “hour”). Thus, the specific estimates are too extensive for presentation here. However, to provide an indication of how soak times are distributed throughout the day, Table III.A-4 presents the distribution of starts by soak time for weekdays for several aggregated soak time intervals.

Table III.A-4. Distribution of Starts by Soak Time: Three Hours During Weekdays

Soak Time (minutes)	7:00 AM	Noon	5:00 PM
0-20	25.7%	48.3%	43.4%
21-40	2.2%	12.0%	12.2%
41-60	1.7%	8.6%	6.4%
61-120	0.3%	7.4%	10.2%
121-240	0.3%	8.8%	7.4%
241-720	27.1%	8.4%	18.9%
720+	42.7%	6.5%	1.4%

The second step in this procedure is to weight the relative start fuel use for each soak time interval by the percentage of starts occurring after that range of soak times. The result is a percentage of an overnight soak equivalent for each hour of the day. These estimates are shown in the second column of Table III.A-5 for each hour of the day. For example, between 6 and 7 a.m., each start uses a volume of fuel equivalent to 68.3% of that associated with a start following an overnight soak. As can be seen, these estimates ranged from a low of 0.25 of an overnight soak at 2 pm to a high of 0.68 of an overnight soak at 6 am. This follows common sense, as most vehicles being started at 6 am in the morning have sat overnight, while many vehicles being started in the middle of the afternoon have been used in the past few minutes or hours. We assume that these estimates are independent of temperature, because the variation in temperature during any particular hour of the day is relatively small.

Table III.A-5. Estimation of Daily Average Overnight Soak Equivalent

Hour of the Day	Overnight Soak, Start Fuel Use Equivalent	Distribution of Starts by Hour	Product of Columns 2 and 3
6 a.m.	68.3%	1.7%	1.2%
7a.m.	68.5%	4.5%	3.1%
8 a.m	51.5%	5.2%	2.7%
9 a.m.	41.1%	5.2%	2.1%
10 a.m	34.2%	5.7%	1.9%
11 a.m.	29.1%	7.1%	2.1%
12 Noon	25.5%	8.7%	2.2%
1 p.m.	25.8%	7.3%	1.9%
2 p.m.	25.1%	8.3%	2.1%
3 p.m.	26.9%	8.5%	2.3%
4 p.m.	25.4%	8.3%	2.1%
5 p.m.	27.8%	7.5%	2.1%
6 p.m.	26.9%	6.1%	1.6%
7 p.m - 5 a.m.	35.5%	16.0%	5.7%
Sum			33.0%

The distribution of starts by hour of the day is also shown in Table III.A-5. By the weighting the overnight soak, start fuel use equivalents by the percentage of starts for each hour of the day, we can calculate the average overnight soak, start fuel use equivalent for each start throughout the day. As shown by the sum of the last column in Table III.A-5, the average start occurring throughout the day uses a volume of fuel equal to 33% of that following an overnight soak. In comparison, the cold start in the FTP has a weighting of 43%.

While this analysis produces a reasonable estimate of the relative number of hot and cold start equivalents during real world driving, it ignores the effect of ambient temperature, which varies throughout the day, as well as between seasons. In order to estimate start fuel use across the nation throughout each day and throughout the year, we estimated the start fuel use for each hour of the day by month for each county in the U.S. and then weighted each estimate by the relative number of starts occurring in each hour of the day and by the relative amount VMT in each month and county. Finally we summed the weighted start fuel use estimates across all hours of the days, months and counties to determine the average start fuel use in terms of a cold start at 75^{o}F.

The national average start fuel use resulting from this process was 0.4665 of an overnight soak at 75^{o}F for gasoline vehicles and 0.4137 for diesels. We can simulate these average start fuel use estimates with a variety of combinations of hot and cold starts at 20°F and 75°F. In order to select a single combination, we used the estimate described in Table III.A-5 above that the daily average start fuel use at a constant temperature is 33.0% of that of a cold start (i.e., that following an overnight soak at that temperature). Assuming that start fuel use after a hot start

(10 minute soak) is negligible and using equations (5) and (6) for relative start fuel use as a function of ambient temperature and soak time, we determined that a 24% weighting of a cold start at 20°F and a 76% weighting of a cold start at 75°F, both multiplied by 33%, has the same start fuel usage as 46.65% of a cold start at 75°F. Thus, for gasoline vehicles, we can simulate the entire distribution of vehicle starts throughout the nation annually by summing the excess start fuel from the cold start for the FTP at 20°F times 0.0904 (24% * 33.0%) and that for the cold start for the FTP at 75°F times 0.2394 (76% * 33.0%).

For diesels, the appropriate weight for the cold start at 20°F is the same as that for gasoline vehicles, 24%. The weight is the same, because the shape of the curves of cold start fuel use for both temperature and soak time for diesels is the same as that for gasoline vehicles. Thus, for diesels, start fuel use under national average conditions is the excess start fuel from the cold start for the FTP at 20°F times 0.0904 plus the cold start for the FTP at 75°F times 0.2394. As mentioned above, cold start fuel use is the difference in total fuel use in Bags 1 and 3 of the FTP, either at 75°F or 20°F. As also mentioned above, we will evaluate the appropriateness of applying these weights to hybrid vehicles in Section III.E below.

b. Trip Length

The previous section estimated start fuel use in terms of total fuel use per start. In this section, we address the frequency of starts per mile of typical on-road driving. The inverse of starts per miles is trip length. The FTP implicitly includes one engine start for every 7.5 miles of driving (i.e., an average trip length of 7.5 miles). This was the average trip length estimated for Los Angeles in 1969. We have updated this estimate using several sources of information.

First, the Draft MOVES2004 model contains an estimate of average trip length in-use.[8] These estimates are shown in Table III.A-6.

Table III.A-6. Trip and Start Related Information in Draft MOVES2004

Vehicle Class	Starts per Day			Miles per Day	Average Trip Length	VMT: 2003 (billion miles)
	Weekday	Weekend	Average Day			
Passenger Cars	7.28	5.41	6.75	29.48	4.37	1,661
Light Trucks < 6000 pounds	8.06	5.68	7.38	35.29	4.78	670
Light Trucks > 6000 pounds	8.06	5.68	7.38	34.08	4.62	251

The estimates of starts and miles per day are based on the results of instrumenting 168 vehicles in Baltimore and Spokane in 1992. The estimates of starts per day for an average day were again determined by weighting the starts per day for weekdays by five-sevenths and for weekends by two-sevenths and summing. The estimates of miles per day were also taken from the Draft MOVES2004 model.[9] Average trip lengths (i.e., miles per start) were determined by dividing miles per day for each vehicle class by the number of starts per day for the average day.

The number of miles per start across all three vehicle classes was determined by dividing total VMT by the total number of starts. From FHWA Highway Statistics 2003, total VMT for LDVs in 2003 was 1,661 billion miles.[10] Total VMT for 2-axle, 4 wheel trucks in 2003 was 998 billion miles. This latter vehicle class includes trucks over 8500 pounds gross vehicle weight rating (GVWR), which are not included within EPA's definition of LDTs. Based on an analysis by Oak Ridge National Laboratory, 92.34% of the VMT by 2-axle, 4-wheel trucks was by vehicles below 8500 pounds GVWR, or LDTs.[11] Thus, LDT VMT in 2003 is estimated as 923 billion miles. Based on this same study, 72.8% of LDT VMT is by LDT1s and LDT2s and 27.2% by LDT3s and LDT4s. Using this breakdown, we estimate LDT1 and LDT2 VMT in 2003 as 670 billion miles and LDT3 and LDT4 VMT as 251 billion miles. Total VMT is then 2,585 billion miles. The total number of starts was estimated by dividing the total VMT for each class by the number of miles per start for each class and then summing. The result was one start for every 4.49 miles, or 0.223 starts per mile.

As mentioned above, the estimates of starts and miles per day came from vehicles operating in the Baltimore and Spokane areas. Therefore, most of this operation was likely urban (not to be confused with "city" when defining driving for fuel economy labeling purposes). These studies were performed along with several others in the early 1990's when EPA was developing the Supplemental FTP rule, which developed and implemented the US06 and SC03 test cycles.[12] In addition to Baltimore and Spokane, vehicle operational information was obtained in Atlanta and Los Angeles. The data obtained in Baltimore and Spokane received primary focus, as the vehicles were recruited from centralized inspection and maintenance stations and the study involved instrumented vehicles. The data from Atlanta involved instrumented vehicles, but the vehicles were recruited via phone contact. While the initial vehicle selection was random, the rate of people declining to participate was higher than at the centralized inspection and maintenance stations. Thus, there is slightly more concern that the final vehicle sample in Atlanta may not be as representative of onroad driving as those in Baltimore and Spokane. The findings from these studies are shown in Table III.A-7.

Table III.A-7. Estimates of In-Use Average Trip Length

Location	Average Trip Length (miles)	
	Instrumented Vehicle Studies	Chase Car Studies
Baltimore - Exeter	4.0	Not Available
Baltimore - Rossville	5.9	Not Available
Baltimore - Combined	4.9	7.5
Spokane	3.6	5.8
Atlanta	6.0	Not Available
Los Angeles	Not Available	7.8

As can be seen from Table III.A-7, there is some variability in average trip length depending on where people reside. People living in the central city section of Baltimore and in the less populated city of Spokane take much shorter trips than those living in the outskirts of Baltimore and the more sprawling city of Atlanta.

Table III.A-7 also shows estimates of average trip lengths from chase car studies conducted at the same time as the instrumented vehicle studies. While chase car studies are ideally suited to study travel on selected roadways, their weakness is that they are not designed to follow a vehicle from trip start to trip end. Thus, they utilize other information in order to piece together trip start and end distances and thus, trip length. As can be seen from Table III.A-7, estimates of average trip length from chase car studies tend to exceed those of instrumented vehicle studies. The latter clearly yield a more accurate estimate, due to the instrument's ability to accurately and precisely determine if the engine is running or not.[e] However, consideration of the chase car studies is useful in that it brings in an additional city, Los Angeles. Based on the relative trip lengths from the chase car studies, it appears that trips in Los Angeles are just slightly longer than in Baltimore and probably shorter than those in Atlanta. Thus, or urban/suburban dwellers, it appears that the average trip length is somewhere between 4 and 6 miles and could be close to 5 miles plus or minus a half mile or so. This estimate includes all trips by these people, those involving both city and highway driving.

No instrumented vehicle studies have been performed in rural areas. Chase car studies have recently been performed in several rural California areas. However, chase car studies do not obtain trip based information, as they do not follow the same vehicle from start to stop. Still, it is likely that trips by rural dwellers are longer than those living in cities.

A second estimate of average trip length in the U.S. is available from the National Household Travel Survey (NHTS).[13] The NHTS was performed in 2001 by the Department of Transportation and statistically surveyed approximately 26,000 households in the U.S. This survey represents the sixth in a series of surveys dating back to 1969. (The name of the survey has changed a few times and the precise survey methods have varied to some degree.) NHTS found that the average trip taken using a personal vehicle in the U.S. was 9.8 miles long. While the average trip length was relatively constant from 1969 to 1990, it has increased roughly one mile since 1990.[14] Thus, the estimates shown in Table III.A-7 above could under-estimate trip length today to some degree.

As noted in the NHTS, the 9.8 mile estimate excludes very long trips, such as those taken on vacations, as well as commercial trips, such as those by taxi cabs, police officers, municipal workers, etc.. These excluded trips could be both shorter and longer than those covered by the survey. However, the number of commercial vehicle operators far exceeds those on vacation at any given time. Thus, the exclusions likely bias the survey results upwards (i.e., result in an over-estimation of national average trip length for all light-duty vehicles and trucks).

As the case with the instrumented vehicle studies, the average trip length of 9.8 miles includes all driving, both city and highway oriented. NHTS does not attempt to split driving into city and highway categories. However, unlike the instrumented vehicle studies, which studied the driving patterns of urban/suburban dwellers, NHTS is intended to cover the entire U.S.

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[e] This is often not the case for recent model hybrid vehicles, whose engines shut off frequently during city driving. However, as the engine is usually turned off for only seconds or minutes, the added fuel due to the perceived engine off is negligible both on the road and per our modeling. This issue did not affect the studies being cited here, as there were no hybrids on the road in the early 1990's.

population, both urban and rural. Per the Federal Highway Administration, 60-63% of car and light truck VMT is urban and suburban and 37-40% is rural. Assuming that urban dwellers drive primarily in urban areas and rural dwellers do likewise, a mile 5 average trip length for 60-63% of all VMT translates into an 8 mile trip length for all driving, even if rural dwellers never shut off their engines. In other words, there appears to be an inconsistency between the two sets of estimates, with the instrumented vehicle studies yielding a shorter trip length than that which can be consistent with the estimate from NHTS. An increase in average trip length of roughly one mile since the time of the instrumented vehicle studies could explain part of this difference. However, some difference still remains. Obviously, the average trip length for rural driving is finite, not infinite.

Based on the NHTS survey questionnaire, we believe that the survey could miss brief stops between the primary trip origination and destination points (e.g., those at gas stations or convenience stores), as well as extremely short trips (e.g., moving a vehicle out of a driveway to allow another vehicle to exit, moving from one parking place at a shopping center to another, or from one shopping center to another just across the street). Using trip information from instrumented vehicles in Baltimore and Spokane (described in more detail below), about 28% of all trips fall into one of these two categories. In the NPRM, we assumed that the NHTS survey missed 28% of the trips, reducing the average trip length 7.66 miles (9.8 miles divided by 1.28).

Since the time of the NPRM, EPA obtained more recent data on the operation of vehicles in Atlanta from Georgia Tech.[15] Georgia Tech has been instrumenting vehicles in the Atlanta area for some time and gathering operational data. As with the previous instrumented vehicle studies, this type of study captures all vehicle trips no matter how short. The major difference between this more recent work and the previous studies is the amount of data being collected. To date, Georgia Tech has collected data on over 620,000 vehicle trips. In contrast, the previous instrumented vehicle studies involved about a week's worth of operation for less than a hundred vehicles per city. Thus, the recent data represents almost two orders of magnitude more data than was evaluated in all of the instrumented vehicle studies described in Table III.A-7 above, albeit from one urban area and one of the most sprawling at that.

The average trip length found for these 620,000 trips around Atlanta was 7.25 miles.[16] The average number of trips per day was 4.62. This means that the vehicles surveyed in Atlanta drove 33 miles per day, which is very close to the national average of 34 miles per day (per MOVES/MOBILE6.2). This is 1.2 miles, or 20% greater than the average trip length of 6.0 miles found in the early 1990's (see Table III.A-7). The series of NHTS have also found a general increase in trip length nationally of about 1.0 mile between 1990 and 2001.[17] Thus, it is likely that the average trip length in the other cities shown in Table III.A-7 have also increased, as well, since the early 1990's when the data was collected. If the average trip length for urban driving was slightly more than 5 miles in the early 1990's, then it is likely more than 6 miles today.

A comparison of the trip lengths resulting from the instrumented vehicle studies and the chase car studies shown in Table III.A-7 indicates that the latter clearly over-estimate trip length. This is likely because chase car studies do not focus on entire vehicle trips, but on vehicle operation along a specified highway segment. However, there is considerable consistency between the relative trip lengths in Baltimore and Spokane based on the instrumented vehicle data and the chase car data. Extrapolating this to Los Angeles, average trip length in Los Angeles appears to be slightly longer than that in Baltimore and considerable longer than that in Spokane. This is not unexpected, given the relative sizes of these cities and their geographical constraints. Including the Atlanta and implied Los Angeles estimates with those from Baltimore and Spokane would produce an average trip length for urban driving of considerably more than 4.49 miles. An overall estimate closer to 5.0 miles would appear to be reasonable for the early 1990's timeframe, given Spokane's relatively unique combination of size and geographical constraints.

Given the growth in average trip length indicated by the two Atlanta studies and the series of NHTS, we estimate that average urban trip length today is roughly 6.2 miles. Assuming an average trip length for urban driving of 6.2 miles, an urban VMT fraction of 0.61, and an overall national average trip length of 9.8 miles from NHTS, the average trip length of highway driving is 135 miles. While not impossible, this is still likely too high. Thus, it still appears likely that the NHTS is missing trips of very short length or combining trips with very short engine off times, though not to the degree assumed in the NPRM analysis. Assuming that the NHTS misses 11% of all trips for these reasons reduces the average trip length for all driving to 8.7 miles and that for rural driving to about 24 miles. This 24 mile figure for an average rural trip is much more reasonable than 135 miles. Therefore, we will update our estimate the national average trip length to be 8.7 miles, from the estimate of 7.7 miles in the NPRM.

This estimate includes all driving, both city and highway oriented. Start fuel use must be split between city and highway driving. Neither MOBILE6.2 nor Draft MOVES2004 includes a direct estimate of the split between city and highway driving as defined for fuel economy labeling purposes. However, such a split can be derived from the driving patterns contained in Draft MOVES2004. This derivation is described next.

Table III.A-8 presents the 14 driving cycles which are used in Draft MOVES2004 to estimate on-road emissions, along with each cycle's average speed.[18] We ran the Draft MOVES2004 model for the entire nation using national default inputs and determined the percentage of driving time which LDVs and LDTs spend in each type of driving (i.e., driving cycle). These percentages are shown in the third column of Table III.A-8.

Table III.A-8. Inventory Driving Cycles in Draft MOVES2004

Cycle	Avg. Speed (mph)	Time Spent During On-Road Driving	Assumed City Percentage
Low Speed	2.5	5.2%	100
New York City	7.1	5.8%	100
LOS EF Non-Freeway	11.6	16.0%	100
LOS CD Non-Freeway	19.2	8.7%	100
LOS AB Non-Freeway	24.8	6.2%	100
LOS G Freeway	13.1	0.1%	100
LOS F Freeway	18.6	0.5%	100
LOS E Freeway	30.5	24.7%	100
LOS D Freeway	52.9	17.4%	0
LOS AC Freeway	59.7	7.3%	0
High Speed Freeway 1	63.2	1.9%	0
High Speed Freeway 2	68.2	2.5%	0
High Speed Freeway 3	76	2.0%	0
Freeway Ramp	34.6	1.7%	44.9

We assigned driving spent in each driving cycle to either city or highway driving, based on its average speed. If the cycle's average speed was less than 45 mph, we assumed that it represented city driving. If the cycle's average speed was greater than 45 mph, we assumed that it represented highway driving. The only exception was driving on freeway ramps. Since freeway driving occurs in both city and highway modes, we assumed that driving on ramps also occurs in both modes. No information exists concerning the use of ramps to access freeways with respect the average speed of the freeway driving at the time. Therefore, we assigned ramp driving to city and highway driving simply in proportion to the percentage of time spent in city freeway driving and highway freeway driving. Therefore, the city percentage of ramp driving was the driving percentages for the LOS E, F, and G freeway cycles (25.3%) divided by the driving percentages for all eight freeway cycles (56.3%), or 44.9%.

In order to calculate the percentage of VMT occurring during city and highway driving, we multiplied the average speed of each cycle by its driving time percentage. We then summed this product of speed and percentage time across all fourteen cycles (31.77 mph). We then multiplied each cycle's product of speed and percentage time by its city percentage and summed again (13.51 mph). The percentage of VMT occurring as city driving is the ratio of these two numbers (13.51/31.77), or 42.6%. We repeated this procedure using the percentage of highway driving (equal to 100% minus the percentage of city driving). The sum of the product of speed, percentage time and highway percentage was 18.26 mph. Thus, the percentage of highway driving is the ratio of 18.26 to 31.77, or 57.4% of VMT.

This city/highway VMT split of 43/57 is quite different from the current 55/45 split. Some analysts have suggested that the 55/45 split should be updated to reflect an even higher city fraction, such as 60/40 to 63/37. The current 55/45 split and the suggested updates are based on FHWA estimates of the urban and rural fractions of national VMT. This assumes that city driving is equivalent to urban driving and highway driving is equivalent to rural driving. There is some merit to this approach for the current city and highway label fuel economy estimates, as the original Los Angeles Road Route No. 4 (the basis for the LA-4 driving cycle included in the FTP) includes some freeway driving which reaches 55 mph. Most of the driving used to develop the HFET occurred on uncongested rural highways.

Generally, we can expect trips dominated by low speed driving to usually involve more starts per mile than high speed trips. The current highway driving cycle, the HFET, contains no cold starts (i.e., infinite trip length). Of course, the 22% adjustment factor applied to the HFET fuel economy to calculate the highway fuel economy label value could account for some cold starts, but no specific trip length is specified. Thus, for simplicity purposes, we assigned an average trip length of 60 miles to highway driving. This is approximate. However, once trip length is over 30-40 miles, start fuel use has a very small effect on fuel economy. Still, a finite trip length for highway driving helps the public to relate to the way highway fuel economy is estimated. Back calculating using the city and highway VMT split of 43/57 and an overall trip length of 8.7 miles, the average trip length for city driving is 4.1 miles.[f] This estimate is 17% longer than the 3.5 mile city trip length estimated in the NPRM.

By itself, this increase in trip length increases 5-cycle city fuel economy for the 615 vehicles in our certification database by 1%. Highway fuel economy remains unchanged, since the average trip length remains at 60 miles. However, this higher 5-cycle city fuel economy will indirectly cause the non-dynamometer adjustment factor to be increased by roughly 0.5% (see Section III.A.5). This factor applies to both city and highway fuel economy. Thus, the net effect of increasing the average trip length of city driving is about a 0.5% increase in 5-cycle city fuel economy and a 0.5% decrease in highway fuel economy.

As it will be useful later in this section, using the information shown in Table III.A-8, we calculated the average speed of city and highway driving. The average speed of city driving is the sum of the product of speed, percentage time and city driving percentage (13.51 mph), divided by the total percentage of city driving (68.0%), or 19.9 mph. The average speed of highway driving is the sum of the product of speed, percentage time and highway driving percentage (18.26 mph), divided by the total percentage of city driving (32.0%), or 57.1 mph. The average speed of all driving represented in Draft MOVES2004 is 31.8 mph.

c. Formula for Start Fuel Use

The total fuel usage in either Bag 1 or Bag 3 can be determined by dividing the number of miles of driving during these portions of the test (3.59 miles for either bag) by the fuel economy measured during that bag. Thus, the equation for start fuel use at either 20°F or 75°F is as follows:

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[f] Given 100 miles of total VMT, 42.6 miles consists of city driving and 57.4 miles of highway driving. At 3.5 miles per city trip, this means 12.14 city trips. At 60 miles per highway trip, this means 0.96 highway trips. The total number of trips is therefore 13.1, for an overall trip length of 7.66 miles (100/13.1).

$$StartFuel_x = 3.6 \times \left(\frac{1}{Bag1\,FE_x} - \frac{1}{Bag3\,FE_x} \right)$$

where x is either 20°F or 75°F.

The equation for start fuel use in terms of gallons per mile is:

For City Fuel Economy:

$$StartFC\ (gallons\ per\ mile) = 0.33 \times \left(\frac{(0.76 \times StartFuel_{75}) + (0.24 \times StartFuel_{20})}{4.1} \right)$$

For Highway Fuel Economy:

$$StartFC\ (gallons\ per\ mile) = 0.33 \times \left(\frac{(0.76 \times StartFuel_{75}) + (0.24 \times StartFuel_{20})}{60} \right)$$

2. Running Fuel Use at 75°F Without Air Conditioning

Running fuel use depends primarily on how the vehicle is driven, particularly the distribution of speed and power. In this section, we develop a description of onroad driving from the Draft MOVES2004 model and then represent this onroad driving using the available dynamometer tests.

a. On-Road Driving Patterns

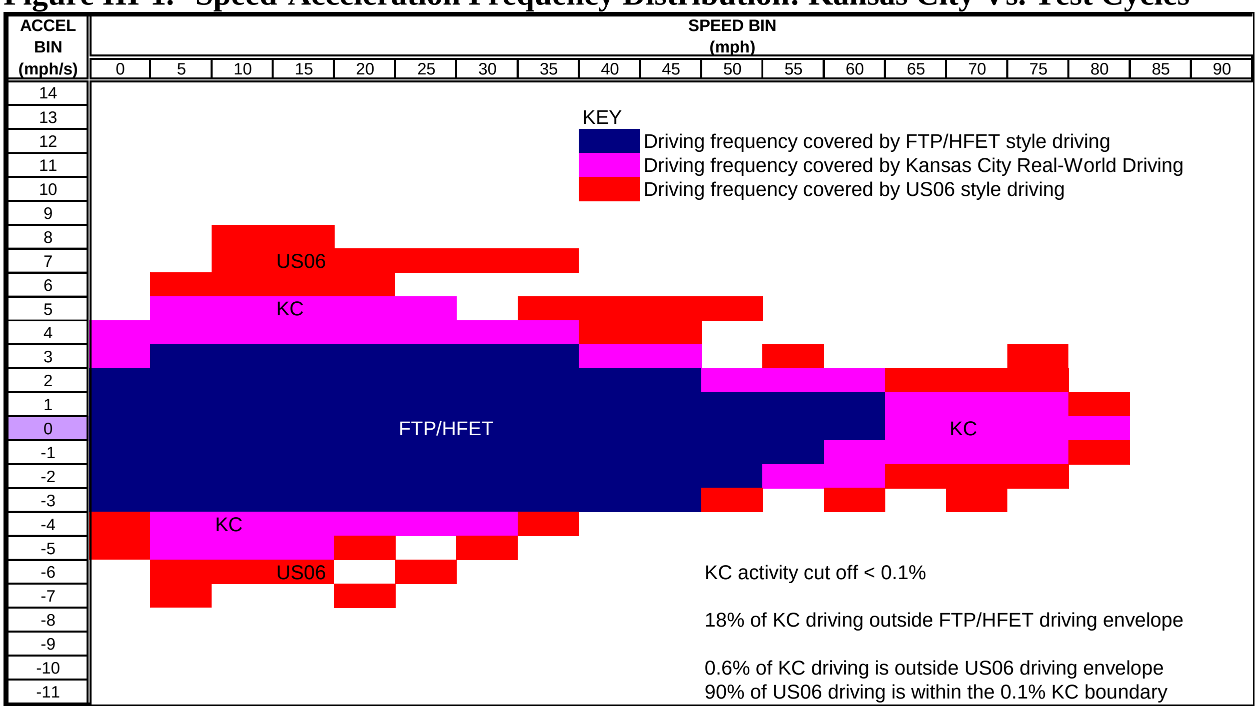
On-road driving patterns have been studied for the purpose of emissions since at least the late 1960's. The driving cycle contained in the FTP, the LA-4, was developed from following typical vehicle operation over a particular road route in Los Angeles in the late 1960's. The HFET was based on instrumented vehicles operated over a rural road route outside of Ann Arbor, Michigan in the late 1970's. The US06 and SC03 cycles, among others, were developed in the early 1990's to augment the LA-4 and HFET cycles. These cycles were based on instrumented vehicles monitored during normal operation in Baltimore, Spokane and Atlanta, which were already discussed in the section on start fuel use above.

Based on the driving data obtained in Baltimore, Spokane and Atlanta, EPA developed three cycles which together did a reasonable job of representing the complete breadth of urban driving: SC03, REP05, and REM01. The SC03 cycle represented driving immediately following engine start-up. REP05 represented high speed and aggressive driving. REM01 represented all other driving. Ignoring changes in driving habits since the early 1990's, on-road fuel economy (at least in urban areas) could be reasonably represented by the fuel economies measured over these three cycles. However, tests over the REP05 and REM01 cycles are not regularly performed during certification. Performing these tests would entail additional testing costs. The SC03 test is only performed with the air conditioning on, so it too would need to be re-performed with the air conditioning turned off. We are primarily interested here in approaches to estimating on-road fuel economy using the current dynamometer tests. Thus, using REP05, SC03 and REM01 to project onroad fuel economy is not a practical option.

The US06 cycle was developed as a concentrated version of the REP05 cycle. Thus, it can conceivably be used in lieu of REP05. The REM01 cycle is similar to the LA-4 cycle which comprises the driving in the FTP. SC03 is only performed with the air conditioning turned on. Thus, it cannot be used to estimate fuel use without air conditioning. SC03 includes higher rates of acceleration than the FTP. However, the US06 cycle includes some low speed driving with higher acceleration rates. Thus, with correct weighting, the US06 test and the warmed up portion of the FTP test should be able to represent much or most of the driving contained in the SC03, REP05 and REM01 cycles.

Our recent testing of driving in Kansas City indicates the need to include the US06 driving pattern in our estimation of fuel economy. This test program and our processing of the data collected are described in detail in Appendix A. We grouped the vehicle operation monitored in Kansas City into combinations of vehicle speed and acceleration and compared it to similar combinations represented in the FTP, HFET and US06 cycles. The breadth or envelope of operation over the FTP and HFET cycles is shown as the innermost area (colored in dark blue in the following figure). The envelope of vehicle operation monitored in Kansas City which exceeds that of the FTP and HFET is shown in purple. Finally, the envelope of the US06 cycle is shown where it exceeds that of the vehicle operation monitored in Kansas City.

Figure III-1. Speed-Acceleration Frequency Distribution: Kansas City Vs. Test Cycles

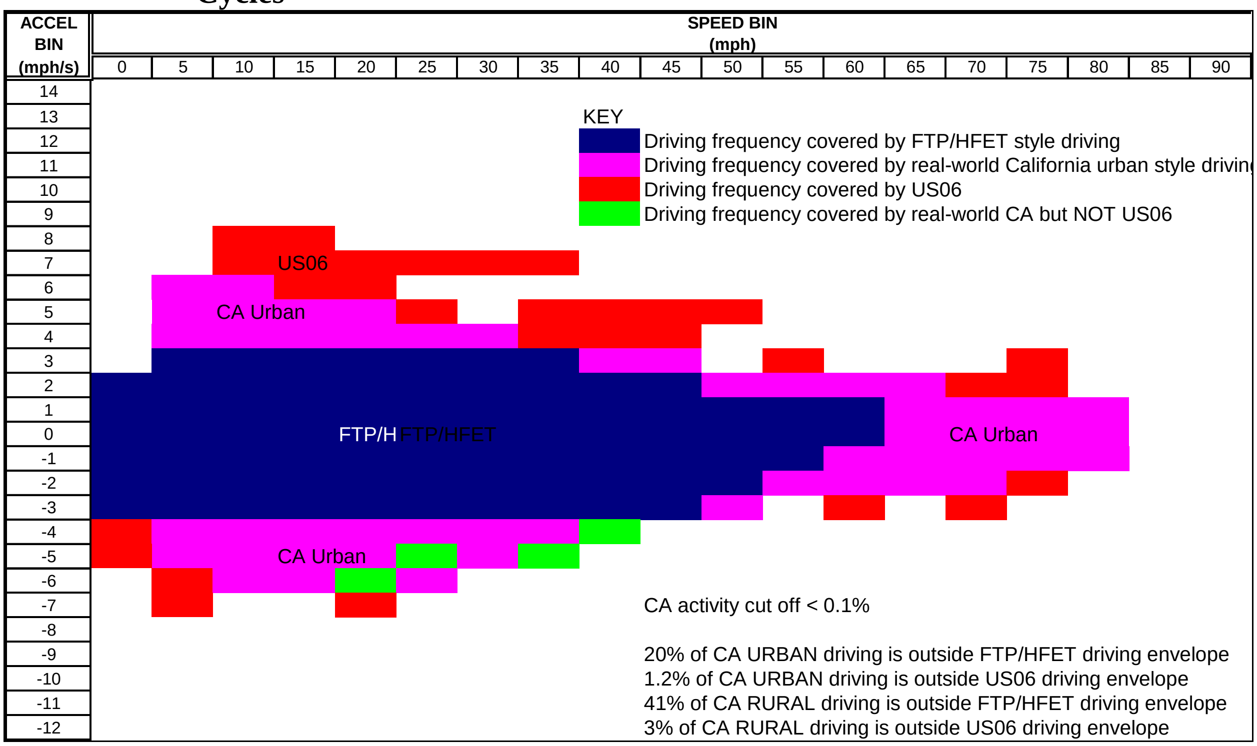


Overall, 18% of the onroad driving activity (time based) in Kansas City fell outside of the FTP/HFET envelope. This corresponds to 33% in VMT terms. As can be seen, most of this operation which exceeds the FTP/HFET envelope has either a higher rate of acceleration or higher vehicle speed. However, only 0.6% of the Kansas City operation fell outside the US06 (0.4% of the VMT).

The SAFD envelopes for hybrid and conventional vehicles did not differ significantly from each other. However, the percentages of driving in the various bins did vary, as will become more evident below when we evaluate the VSP frequency distributions for the two types of vehicles.

Recent chase car studies of driving in California show even more operation outside of the FTP/HFET envelope. (The details of these test programs are also discussed in Appendix A.) The combinations of speed and acceleration for the monitored California urban driving are shown in the following figure.

Figure III-2. Speed-Acceleration Frequency Distribution: Urban California Vs. Test Cycles



As can be seen, the breadth of California urban driving which exceeds the FTP/HFET envelope is much more expansive than that found in Kansas City. Onroad driving includes much higher speeds and both higher and lower rates of acceleration. Overall, 20% of California urban driving lies outside the FTP/HFET envelope (34% of the VMT). Just over 1% fell outside the US06 envelope (1.3% of the VMT). Rural driving was found to be more aggressive than urban driving. While not shown in the above figure, 3% of the rural driving was outside the US06 envelope.

Both the MOBILE6.2 and Draft MOVES2004 models contain estimates of on-road driving. MOBILE6.2 describes driving in a more traditional fashion by assigning VMT to various driving cycles, like those listed in Table III.A-8 above. This is very acceptable for estimating emission inventories. However, it is not straightforward to convert driving over such cycles to driving over the five available dynamometer cycles or bags. Average speed and power are available for each cycle. However, with only two degrees of freedom, one cannot determine weightings for five dynamometer cycles. A more detailed distribution of speed and power is necessary. This brings us to the approach taken in Draft MOVES2004, which is more amenable to the task faced here.

Draft MOVES2004 takes a much different approach to describing on-road driving than previous EPA emission inventory models, for example, MOBILE6.2. While starting with whole driving cycles, like those listed in Table III.A-8 above, it goes further by breaking down vehicle operation on a second by second basis into 17 categories or bins. One bin (Bin 0) contains significant decelerations. Another bin (Bin 1) contains idling operation. The other 15 bins contain brief or modest decelerations, cruising operation and accelerations. The 15 bins are broken down into three sets of bins by vehicle speed: Bins 11-16 contain operation at 1-25 mph, Bins 21-26 contain operation at 25-50 mph, Bins 33-36 contain operation at 51 mph or faster. These three sets of bins are further sub-divided according to the power required of the engine divided by vehicle mass. This ratio is termed vehicle specific power, or VSP, and has the units of kilowatt per megagram (kW/Mg). The VSP bins are described in Table III.A-9.

Table III.A-9. VSP-Speed Bins in Draft 2004MOVES

Bin Label	Vehicle Speed (mph)	Vehicle Specific Power (kW/Mg)
MOVES		
0	Deceleration	---
1	Idle	---
11	1-25	<0
12		0-3
13		3-6
14		6-9
15		9-12
16		>12
21	25-50	<0
22		0-3
23		3-6
24		6-9
25		9-12
26		>12
33	>50	<6
35		6-12
36		>12

The three bins with open ended power levels (bins 16, 26, and 36) have lower limits of 12 kW/Mg. Power during onroad driving can exceed 50 kW/Mg. Nearly 35% of the US06 cycle falls into bin 36. Therefore, it is useful to split these bins up further into smaller power increments. This is being considered for the next version of the MOVES model.

Here, we expanded the set of 17 VSP bins by splitting bins 16, 26, and 36 into four bins, for a net increase of 9 bins. The three speed ranges stay the same. However, instead of bin x6 (i.e., 16, 26, and 36) including all power levels above 12 kW/Mg, bin x6, x7, and x8 will all include a range in power of 3 kW/Mg, while bin x9 will be open ended. The expanded set of VSP bins is shown along with that from Draft MOVES2004 in Table III.A-10.

Table III.A-10. Expanded Set of 26 VSP-Speed Bins

Bin Label		Vehicle Speed (mph)	Vehicle Specific Power (kW/Mg)
MOVES	Expanded Set		
0	0	Deceleration	---
1	1	Idle	---
11	11	1-25	<0
12	12		0-3
13	13		3-6
14	14		6-9
15	15		9-12
16	16		12-15
	17		15-18
	18		18-21
	19		>21
21	21	25-50	<0
22	22		0-3
23	23		3-6
24	24		6-9
25	25		9-12
26	26		12-15
	27		15-18
	28		18-21
	29		>21
33	33	>50	<6
35	35		6-12
36	36		12-15
	37		15-18
	38		18-21
	39		>21

Now that the VSP concept has been introduced, it will be easier to understand how Draft MOVES2004 describes on-road driving, which is accomplished in three steps. First, a VSP frequency distribution is developed for each of the fourteen inventory cycles listed in Table III.A-8 above. Most of these inventory cycles were developed from the on-road driving data obtained in Baltimore, Spokane and Atlanta in the early 1980's. The three highest speed freeway cycles have been added more recently to represent driving at speeds higher than those typical of this earlier timeframe, since the highest speed limit during the time of these studies was 55 mph. Each VSP distribution shows the percentage of time spent driving in each of the 26 VSP bins. Different vehicles will produce slightly different VSP distributions. However, because VSP is defined as the ratio of required power to vehicle weight, the differences in VSP across various vehicles are relatively small for a given driving pattern. Draft MOVES2004 includes VSP distributions for typical LDVs and LDTs. We have combined these two sets of VSP distributions using a mix of 50% cars and 50% light trucks, which represents the split of onroad VMT in calendar year 2004 from MOBILE6.2. These LDV/LDT weighted VSP distributions are shown in Tables III.A-11 and III.A-12. (LOS stands for level of service, or volume of traffic. LOS A involves the least volume of traffic. LOS G is the most congested.)

Table III.A-11. VSP Frequency Distributions for Onroad driving Cycles in MOVES

VSP Bin	Low Speed	New York City	LOS EF Non-Freeway	LOS CD Non-Freeway	LOS AB Non-Freeway	LOS G Freeway	LOS F Freeway
0	2.2%	11.0%	14.3%	14.5%	13.0%	8.5%	11.3%
1	49.7%	41.7%	33.9%	22.4%	15.1%	4.4%	3.6%
11	15.3%	13.1%	7.5%	7.3%	3.8%	29.2%	16.5%
12	32.6%	17.7%	13.9%	7.5%	6.4%	34.0%	23.5%
13	0.3%	7.9%	6.0%	4.3%	4.2%	11.4%	11.5%
14	0.0%	2.5%	3.3%	4.4%	2.8%	3.8%	4.1%
15	0.0%	2.2%	2.5%	2.4%	2.9%	1.3%	1.2%
16	0.0%	0.8%	1.1%	0.8%	0.9%	0.0%	1.8%
17	0.0%	0.3%	0.0%	0.2%	0.3%	0.0%	0.5%
18	0.0%	0.5%	0.0%	0.3%	0.1%	0.0%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
21	0.0%	0.2%	4.1%	7.7%	8.7%	0.5%	5.3%
22	0.0%	0.4%	2.1%	7.5%	7.1%	0.8%	5.4%
23	0.0%	1.2%	3.9%	5.5%	10.3%	1.8%	4.1%
24	0.0%	0.2%	2.7%	6.0%	8.3%	2.1%	3.2%
25	0.0%	0.2%	2.5%	4.1%	3.8%	2.1%	3.7%
26	0.0%	0.2%	0.9%	3.1%	2.4%	0.3%	2.3%
27	0.0%	0.0%	1.2%	1.3%	0.9%	0.0%	1.2%
28	0.0%	0.0%	0.0%	0.5%	0.8%	0.0%	0.5%
29	0.0%	0.0%	0.2%	0.2%	0.3%	0.0%	0.3%
33	0.0%	0.0%	0.0%	0.0%	2.8%	0.0%	0.0%
35	0.0%	0.0%	0.0%	0.0%	3.2%	0.0%	0.0%
36	0.0%	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%
37	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%
38	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
39	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table III.A-12. VSP Frequency Distributions for Onroad driving Cycles in MOVES

VSP Bin	LOS E Freeway	LOS D Freeway	LOS AC Freeway	High Speed Freeway 1	High Speed Freeway 2	High Speed Freeway 3	Freeway Ramp
0	11.2%	5.2%	1.4%	2.1%	3.3%	0.9%	10.5%
1	1.8%	0.0%	0.0%	0.0%	0.0%	0.0%	6.8%
11	7.8%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%
12	10.5%	0.0%	0.0%	0.0%	0.0%	0.0%	4.1%
13	7.5%	0.0%	0.0%	0.0%	0.0%	0.0%	4.5%
14	4.6%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%
15	2.1%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%
16	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
21	7.6%	4.7%	0.2%	0.0%	0.0%	0.0%	8.3%
22	11.0%	4.9%	0.5%	0.0%	0.0%	0.0%	4.4%
23	5.3%	5.4%	0.6%	0.0%	0.0%	0.0%	4.1%
24	5.4%	4.8%	0.5%	0.0%	0.0%	0.0%	4.2%
25	3.8%	4.3%	0.5%	0.0%	0.0%	0.0%	6.4%
26	3.4%	3.9%	0.5%	0.0%	0.0%	0.0%	5.3%
27	0.5%	1.3%	0.5%	0.0%	0.0%	0.0%	4.1%
28	0.7%	0.5%	0.1%	0.0%	0.0%	0.0%	3.3%
29	0.4%	1.0%	0.8%	0.0%	0.0%	0.0%	5.5%
33	4.2%	17.4%	23.2%	18.5%	9.6%	7.4%	9.2%
35	5.8%	18.1%	30.2%	29.9%	22.2%	14.9%	3.2%
36	2.1%	9.1%	10.7%	13.9%	15.0%	7.3%	2.6%
37	2.5%	7.2%	12.8%	12.0%	18.0%	11.9%	0.8%
38	1.2%	5.8%	9.1%	10.5%	12.2%	18.6%	2.1%
39	0.4%	6.4%	8.4%	12.9%	19.6%	39.0%	2.0%

Second, a distribution of average speeds by hour of the day and road segment for the area of interest are developed. In urban areas, these estimates come from travel demand models for five specific urban areas (Ada County, ID, Charlotte, NC, Chicago, IL, Houston, TX, and New York, NY).[19] Travel in other urban areas is assigned to one of the five modeled areas. In rural areas, these estimates come from chase car data recently obtained in California. Based on average speed and roadway type, travel is assigned to two of the fourteen inventory cycles (listed in Table III.A-8 above). The two cycles selected are those which have average speeds which most closely match the average speed of that roadway type during that hour of the day. Cycles are chosen which also represent driving on the same roadway type, if they are available.[g] The weighting of the two cycles are determined so that the average speed in-use is matched exactly. Then, the VSP distributions of these two cycles are combined using these same weightings.

Third, these combinations of VSP distributions for the various cycles are aggregated over the geographical and temporal intervals of interest, weighting each by the amount of driving

[g] Sometimes, higher speed driving on non-freeways in rural areas exceeds the average speed of the available non-freeway driving cycles. In this case, freeway cycles are used.

occurring over each roadway segment and time interval. Here, we are concerned with national, annual average driving. Thus, Draft MOVES2004 was run for the nation as a whole for an entire year and the distribution of driving over the various inventory cycles was output.

Table III.A-13 shows the resulting distribution of on-road driving into the 14 inventory cycles. Three distributions are shown. The first distribution represents all U.S. driving, which was the direct output from Draft MOVES2004. The second represents city driving. In this case, the all U.S. driving percentages were multiplied by the city percentages shown in Table III.A-8 above and normalized to sum to 100%. The third shows the distribution for highway driving, using 100% minus the city percentages shown in Table III.A-8 above. Also shown is the average speed for each cycle. Weighting the average speed of each cycle by its percentage of driving time also yields the average speed of that type of driving (e.g., city). These speeds are shown in the last row of the table.

Table III.A-13. Distribution of Onroad Driving Patterns: Draft MOVES2004

Inventory Cycle	Average Speed (mph)	Distribution of Driving Time		
		All Driving	City Driving	Highway Driving
Low Speed 1	2.5	5.2%	7.7%	0.0%
New York City	7.1	5.8%	8.6%	0.0%
LOS EF Non-Freeway	11.6	16.0%	23.5%	0.0%
LOS CD Non-Freeway	19.2	8.7%	12.8%	0.0%
LOS AB Non-Freeway	24.8	6.2%	9.1%	0.0%
LOS G Freeway	13.1	0.1%	0.2%	0.0%
LOS F Freeway	18.6	0.5%	0.7%	0.0%
LOS E Freeway	30.5	24.7%	36.3%	0.0%
LOS D Freeway	52.9	17.4%	0.0%	54.5%
LOS AC Freeway	59.7	7.3%	0.0%	22.8%
High Speed Freeway 1	63.2	1.9%	0.0%	5.8%
High Speed Freeway 2	68.2	2.5%	0.0%	7.7%
High Speed Freeway 3	76.0	2.0%	0.0%	6.4%
Freeway Ramp	34.6	1.7%	1.1%	2.9%
Average Speed (mph)	---	19.9	57.1	31.8

The average speed of city driving, 19.9 mph, is just slightly higher than that of the FTP, 19.6 mph. The average speed of highway driving is well above that of both the HFET and US06 cycles, but slightly below the highway portion of the US06 cycle. As described in section III.A.1 above, according to this methodology, the percentage of national VMT that is like city driving is 42.6% and that which is like highway driving is 57.4%. As also mentioned in section III.A.1 above, we evaluate two alternatives which assign portions of the driving over the LOS D Freeway to city driving in section III.E.2 below. These two options increase the city percentage of national VMT to 50% and 55%, respectively.

We then weighted the VSP distributions of each inventory cycle (from Table III.A-11 and III.A-12) by the percentage of driving represented by each cycle (from Table III.A-13). This produced VSP distributions for all U.S. driving, city driving and highway driving. These three VSP distributions are shown in Table III.A-14.

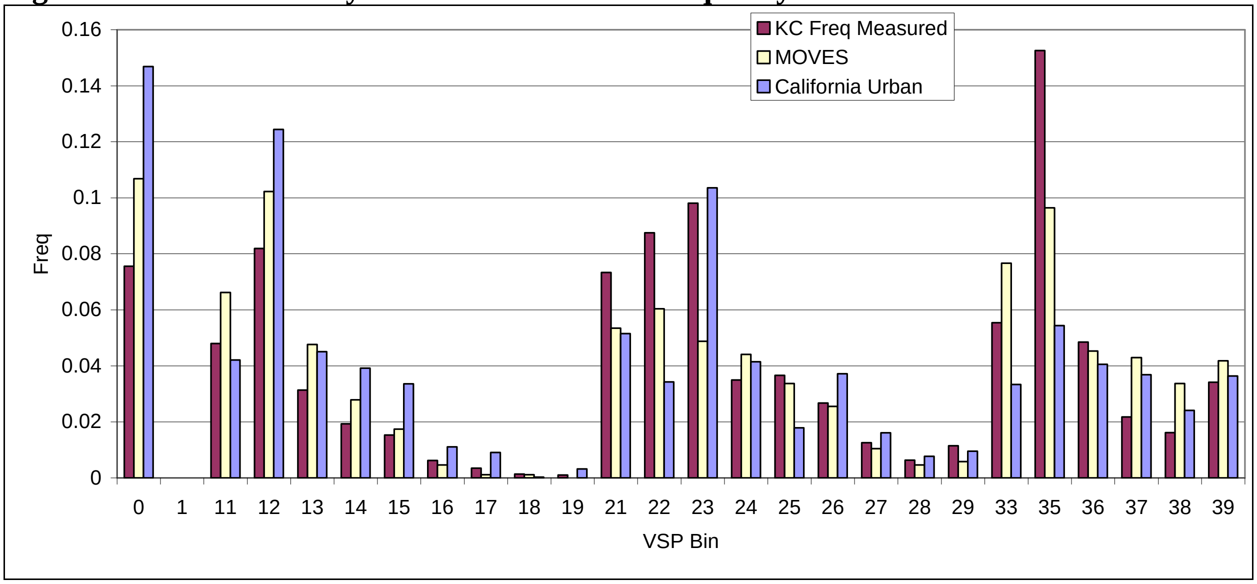
Table III.A-14. VSP Distributions for U.S. Driving (% of time)

VSP Bin	City	Highway	All U.S.
0	11.8%	3.9%	9.2%
1	20.4%	0.2%	13.9%
11	8.3%	0.1%	5.7%
12	13.0%	0.1%	8.8%
13	6.0%	0.1%	4.1%
14	3.5%	0.1%	2.4%
15	2.2%	0.0%	1.5%
16	0.6%	0.0%	0.4%
17	0.1%	0.0%	0.1%
18	0.1%	0.0%	0.1%
19	0.0%	0.0%	0.0%
21	5.5%	2.8%	4.6%
22	6.2%	2.9%	5.2%
23	4.7%	3.2%	4.2%
24	4.2%	2.9%	3.8%
25	3.0%	2.6%	2.9%
26	2.2%	2.4%	2.2%
27	0.8%	0.9%	0.9%
28	0.4%	0.5%	0.4%
29	0.3%	0.9%	0.5%
33	1.9%	16.7%	6.6%
35	2.3%	21.0%	8.3%
36	1.1%	10.1%	3.9%
37	0.9%	9.8%	3.7%
38	0.5%	8.0%	2.9%
39	0.2%	10.7%	3.6%

These VSP distributions represent national average city and highway driving in the U.S. The next step is to determine what combination of the five dynamometer cycles best matches each VSP distribution.

The following figure compares the VSP distribution of vehicle operation monitored in Kansas City to that in Draft MOVES2004.

Figure III-3. Kansas City and California VSP Frequency Distributions vs. MOVES

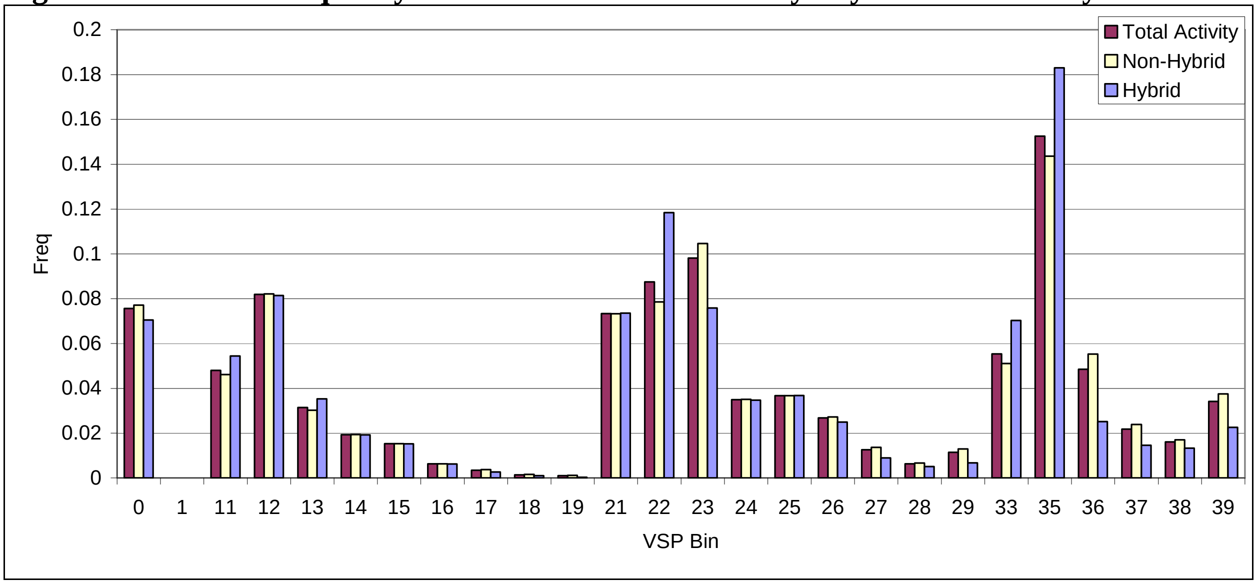


The match in trends is reasonable, though Draft MOVES2004 projects roughly 4% more activity in the high speed, high power Bins 36-39 and 4% less activity in the lower power Bin 35.

This figure also shows the VSP distribution of the chase car data study conducted in Los Angeles in 2000 in this figure. The portion of driving found the Bins 36-39 in Los Angeles matches that in MOVES2004, though there is about 1% less operation in Bins 26-29. One must be cautious when comparing activity data from instrumented vehicles and chase cars. Chase cars do not follow drivers throughout their entire trip, so operation on local neighbor roads is often missed. Also, the VSP distribution from Draft MOVES2004 includes both urban and rural operation, while those of Kansas City and Los Angeles are primarily urban. This could introduce some differences, as well.

The following figure shows the VSP frequency distributions for three groups of Kansas City vehicles: all vehicles, hybrids and non-hybrids. We removed idle (bin 0) prior to calculating the VSP distributions for two reasons. One, idle percentages were extremely high and if depicted in the figure, would have made the rest of the bars difficult to read. Second, given that little fuel is consumed during idle, including the percentage of time at idle distorts the comparison of those VSP bins where fuel consumption is more significant.

Figure III-4. VSP Frequency Distributions in Kansas City: Hybrids vs. Non-Hybrids



As can be seen from a close look at the operation in the higher power bins (x6-x9), the driving of hybrids tends to be less aggressive than that of conventional vehicles. The percentage of time spent driving in bins 26-29 and 36-39 is 5-6% lower for hybrids than conventional vehicles. This is of interest, as this study is likely to be the first to examine the relative operation of conventional and hybrid vehicles. If there was something about hybrid vehicles which always led them to be operated less aggressively, this might need to be considered in developing their fuel economy label value.

The possible explanations for this difference are discussed in Appendix A. Most of the possible explanations imply that the difference could diminish or disappear in the future. This is the first study of the onroad operation of hybrids in the hands of typical owners. Only about 45 hours of operation were studied. Thus, there is significant uncertainty in the difference found in the operation of conventional and hybrid vehicles. As discussed in Section III.A, we are in the process of obtaining a large volume of operational data obtained in Atlanta. Some hybrid vehicles may be included in this database. We plan to compare the operation of conventional and hybrid vehicles in that study as soon as we receive the data. Still, the potential impact of the difference in driving behavior for the two types of vehicles is examined in Section III.E.4.

b. Representative Mix of Dynamometer Driving Cycles

The five current certification dynamometer tests include four distinct driving cycles, or patterns of driving. In addition, the FTP includes two distinct driving patterns, as emissions over the FTP is usually collected in two separate “bags”. Two basic characteristics of these driving patterns are depicted in Table III.A-15: average speed and a basic measure of the average power required by the engine.

Table III.A-15. Driving Characteristics of the Current Dynamometer Tests

Cycle	Average Speed (mph)	Average Power* (mph^2 per second)
FTP (Bags 2 and 3)	19.6	40.9
FTP: Bag 3	25.6	53.6
FTP: Bag 2	16.1	33.8
HFET	48.2	34.9
US06	48.0	104.3
US06: City Bag	21.7	152.9
US06: Highway Bag	61.2	78.2
SC03 (run with air conditioning on)	21.5	49.2
Cold Temperature FTP (same driving cycle as FTP)	19.6	40.9

* Power defined as velocity times the change in velocity per second during cruise or accelerations. Power is set equal to zero during decelerations and not considered in the determination of average power.

The FTP and the cold temperature FTP both involve the same driving cycle, just at different ambient temperatures. Thus, their average speeds and power are identical, both for the total cycle and for each bag of emissions measured. The FTP and SC03 involve distinct, but similar driving cycles. Both are low speed cycles having similar average speeds and power levels. As the SC03 test is only run with the air conditioning on and all the other tests are run with air conditioning off, it is not possible to isolate the effect of the driving cycle differences between the FTP and SC03 tests directly. Thus, this leaves five distinct driving patterns which can be used to represent typical U.S. driving: Bag 2 of the FTP, Bag 3 of the FTP, HFET, City Bag of US06 and Highway Bag of US06.

As shown in Table III.A-15, both Bags 2 and 3 of the FTP are low speed cycles, but their average power requirements differ by a factor of 1.7. As will be seen below, it may be useful to consider each bag separately in simulating typical city and highway driving.

The current US06 test currently consists of 600 seconds of driving and the emissions are collected in one bag (i.e., one single collection of pollutants emitted during the test). Thus, the fuel economy is measured over the entire cycle. The US06 driving cycle consists of 5 hills, or 5 driving segments which begin and end with the vehicle at idle.[h] The first hill of the cycle peaks at 44.2 mph, while the last three hills peak at 28.5, 28.0 and 51.6 mph. All of these hills are also relatively short in duration. These hills are indicative of city like driving. The second and third hills peak at 70.6 and 80.3 mph, which are more indicative of highway driving. The second hill is relatively short (roughly 90 seconds), while the third hill comprises most of the US06 test (roughly 360 seconds).

[h] A "hill" within a driving cycle is a segment of driving which starts and finishes with the vehicle at rest (zero speed). The term hill comes from the view of a driving trace where vehicle speed is plotted versus time. As the vehicle accelerates, its speed increases, causing this trace to climb up a hill. Then as the vehicle decelerates, it proceeds down the hill.

As discussed in the preamble to the proposed rule, we are proposing that two separate emission measurements be made during the US06 cycle to better estimate city and highway fuel economy. To best distinguish between city and highway like driving, we would group hills 1, 4, and 5 into a city bag and hills 2 and 3 into a highway bag. However, the total length of time of hill 1 is quite short, only 45 seconds. In some cases, emissions can be collected into a bag at the beginning of a test (i.e., hill 1), emissions then collected into a second bag (i.e., hills 2 and 3), and then emissions collected into the first bag again (i.e., hills 4 and 5). In this case, there should be sufficient emission sample in each of the two bags to measure accurately with today's equipment. However, in some cases, a manufacturer might have to collect the sample in three bags, with the first bag only containing the emissions from the first hill. We are concerned that this is not sufficient time to generate enough emissions to measure accurately. Including hill 2 in the first bag triples the driving time and ensures the ability to accurately measure emissions and fuel use. Thus, we are proposing to place the second hill into the city portion of the cycle, essentially separating the measurement of emissions during the third hill from the other four hills. Bag 1 would consist of hills 1 and 2, Bag 2 would consist of hill 3 and Bag 3 would consist of hills 4, and 5. While this incorporates some highway like driving into the "city" portion of the segregated US06 test, as will be shown below, this is still a much improved segregation of city and highway like driving than the US06 cycle as a whole.

For example, even with the second hill included in the city portion, the average speed of the city portion of US06 is only 27.7 mph. The average speed of the highway portion of US06 is 61.2 mph. The average speed of the entire cycle is 48.0 mph. Thus, separating the cycle in this way creates two dramatically different driving cycles, each of which falls much more clearly into our definitions of city and highway driving than the US06 cycle as a whole. To avoid any confusion with the bags of the FTP, we will refer to the city and highway portions of the US06 cycle as US06 city and US06 highway. Overall, seconds 0-131 and 496-600 of the cycle would comprise the city bag and seconds 132-495 would comprise the highway bag. The description of the hills within US06 and their designation is summarized in the table below.

Table III.A-16. Split of US06 Cycle into City and Highway Portions

Hill	Portion of Driving Cycle (cumulative seconds)	Maximum Speed (mph)	Designation
1	0-43	44.2	City
2	44-131	70.7	City
3	132-495	80.3	Highway
4	496-563	29.8	City
5	564-600	51.6	City

We evaluate the impact of a more ideal separation of US06 into city and highway driving in section III.E below. There, the US06 highway bag contains hills 2 and 3 and the US06 city bag contains hills 1, 4 and 5.

With the split of US06 into two bags, we have available fuel economy estimates for five distinct driving patterns:

1) Bags 1 and 3 of the FTP;
2) Bag 2 of the FTP;

3) HFET;
4) City portion of US06; and
5) Highway portion of US06.

We propose to combine the results of these five tests to represent typical city and highway driving patterns.

The VSP distributions for the four complete dynamometer cycles plus individual bags of the FTP and US06 cycles are shown in Table III.A-17. As was the case for the Draft MOVES2004 inventory cycles, these VSP distributions represent a 50-50 mix of cars and light trucks.

Table III.A-17. VSP Distributions for Dynamometer Cycles (% of time)

BinID	LA4	HFET	US06	US06 City	US06 Hwy	SC03	Bag 3	Bag 2
0	12.0%	3.5%	16.8%	32.6%	7.1%	10.5%	13.3%	11.2%
1	18.6%	0.7%	7.5%	14.3%	2.5%	19.7%	18.8%	18.5%
11	6.4%	0.0%	0.7%	1.3%	0.3%	3.7%	2.8%	8.5%
12	10.6%	0.1%	0.8%	1.7%	0.3%	9.2%	4.4%	14.3%
13	8.0%	0.3%	0.3%	0.9%	0.0%	5.0%	3.0%	10.9%
14	5.0%	0.1%	0.5%	1.3%	0.0%	2.4%	2.4%	6.5%
15	2.3%	0.5%	0.2%	0.4%	0.0%	2.0%	2.9%	1.9%
16	0.7%	0.1%	1.0%	2.2%	0.3%	2.1%	1.7%	0.2%
17	0.1%	0.0%	0.8%	2.2%	0.0%	0.0%	0.4%	0.0%
18	0.0%	0.0%	0.5%	1.3%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	1.7%	3.5%	0.5%	0.0%	0.0%	0.0%
21	4.4%	4.1%	1.4%	3.3%	0.3%	7.7%	4.6%	4.3%
22	10.9%	3.6%	0.7%	1.5%	0.1%	9.6%	7.3%	13.0%
23	9.5%	12.4%	0.8%	1.7%	0.1%	10.3%	12.4%	7.9%
24	2.9%	17.3%	0.1%	0.2%	0.0%	6.6%	4.5%	2.0%
25	1.5%	7.5%	0.4%	1.1%	0.0%	3.9%	2.7%	0.8%
26	0.7%	2.5%	0.2%	0.4%	0.0%	4.0%	2.0%	0.0%
27	0.2%	0.4%	0.7%	1.5%	0.1%	0.0%	0.6%	0.0%
28	0.3%	0.3%	1.2%	2.4%	0.4%	0.0%	0.9%	0.0%
29	0.2%	0.0%	4.5%	9.1%	1.6%	0.0%	0.6%	0.0%
33	1.6%	6.1%	7.8%	4.6%	9.9%	1.8%	4.3%	0.0%
35	2.6%	32.3%	14.1%	3.7%	20.7%	0.6%	7.1%	0.0%
36	1.1%	6.0%	8.6%	0.4%	13.8%	0.5%	2.9%	0.0%
37	0.1%	2.0%	10.3%	0.9%	16.2%	0.4%	0.3%	0.0%
38	0.2%	0.1%	6.6%	0.9%	10.2%	0.0%	0.5%	0.0%
39	0.0%	0.0%	12.0%	6.5%	15.5%	0.2%	0.0%	0.0%

We then performed a set of linear regressions of the VSP distributions of the various dynamometer cycles against the city and highway VSP distributions. To maximize the ability of the dynamometer cycles to predict on-road fuel economy, we weighted the squared error in each VSP bin by its average rate of fuel consumption in each bin. We could not use the Draft MOVES2004 fuel rates directly, since they only exist for 17 VSP bins. Given this, we developed several sets of 26-bin VSP fuel rates, as each approach had its relative strengths and weaknesses.

One set of fuel rates was based on the results of an EPA study performed on 15 cars in 2001.[20] This study instrumented 15 passenger cars with portable emission measurement devices and measured vehicle activity and fuel economy on a second by second basis. The strength of this study is that it consisted of onroad testing, though the selection of vehicles and drivers were not necessarily representative of those in the U.S. The weakness is that only cars were tested; no light trucks.

Another set of fuel rates was taken from a recent testing program conducted in Kansas City. This program is described in detail in Appendix A. We used the average fuel rates for the 63 non-hybrid vehicles tested in the program, 30 cars and 33 light trucks.

A final set of fuel rates was developed by extrapolating the Draft MOVES2004 fuel rates (average of a 50/50 mix of cars and light trucks). The fuel rates for the x5 bins and those of lower power were takes directly from those in Draft MOVES2004. The x6, x7, x8 and x9 bins were determined by multiplying the x5 bin fuel rates from Draft MOVES2004 by the ratios of the fuel rates in the higher power bins to the fuel rates of the analogous x5 bins from the EPA 15 car study.

These four alternative sets of fuel rates are shown in Table III.A-18.

Table III.A-18. 26-Bin VSP Fuel Rates (gram per second)

VSP Bin	EPA 15 Car	Kansas City	Extrapolated MOVES	
			EPA 15 Car	Kansas City
0	0.295	0.412	0.391	0.391
1	0.286	0.384	0.326	0.326
11	0.382	0.454	0.509	0.509
12	0.610	0.641	0.660	0.660
13	0.911	1.122	0.978	0.978
14	1.223	1.406	1.260	1.260
15	1.516	1.715	1.536	1.536
16	1.897	2.006	1.797	1.921
17	2.161	2.172	1.945	2.189
18	2.591	2.358	2.112	2.624
19	3.447	2.296	2.056	3.491
21	0.457	0.593	0.659	0.659
22	0.637	0.833	0.766	0.766
23	0.857	0.986	0.971	0.971
24	1.040	1.180	1.264	1.264
25	1.379	1.352	1.629	1.629
26	1.709	1.631	1.965	2.019
27	2.053	1.917	2.310	2.426
28	2.346	2.272	2.737	2.772
29	3.686	2.424	2.921	4.356
33	1.004	1.069	1.001	1.001
35	1.430	1.486	1.573	1.573
36	1.813	1.753	1.856	1.994
37	1.985	1.937	2.051	2.183
38	2.163	1.948	2.061	2.379
39	3.315	2.309	2.444	3.646

We selected the fuel rates from the Kansas City test program over the other two sets of fuel rates. The Kansas City fuel rates are based on a mix of cars and light trucks which were selected randomly from vehicle registrations of 2001 and later model year vehicles. The vehicles were also driven by their owners in normal operation. The 15 car test program only included cars, no light trucks. Also, the operators of the vehicles were EPA employees or contractors who were aware of the purpose of the test program. The fuel rates from Draft MOVES2004 include data from a large number of cars and light trucks. However, the extrapolation of the fuel rates for the 12 highest power bins is based on data from the 15 cars. Thus, the fuel rates from the Kansas City program are the most balanced and representative of actual onroad operation of the three sets of fuel rates.

We performed the regressions using the regression function in Excel. The intercept was set to zero. This function does not provide for weighting the residuals. Thus, we incorporated this weighting by multiplying the VSP frequencies in both Tables III.A-12 and III.A-15 by the square root of the fuel rate for each VSP bin from the middle column of Table III.A-18. We also performed the regressions in a stepwise fashion. For both city and highway driving, we started with all five dynamometer driving cycles in the regression. Any driving cycle with a negative coefficient was dropped from the regression. If two or more cycles had negative coefficients, the cycle (of this group of cycles with negative coefficients) with the lowest p-value (most statistically significant) was dropped first. The regression was then rerun. Once all cycles with negative coefficients were deleted, we continued to drop the cycle with the highest p-value until the adjusted r-squared value began to decrease. We then selected the set of cycles and their coefficients which produced the greatest adjusted r-squared value. The final set of coefficients generally did not sum to 1.0. Therefore, we normalized them to sum to 1.0. The results of the final regressions for city and highway driving are shown in the first two columns of numbers in Table III.A-19 below. Cycle coefficients were rounded to the nearest percentage.

Table III.A-19. Best-Fit Combinations of Dynamometer Cycles

Cycles	Time Basis			Mileage Basis		
Coefficients	City	Highway	All	City	Highway	All
Bag 3 FTP	32%	0%	30%	41%	0%	24%
Bag 2 FTP	60%	0%	38%	48%	0%	19%
HFET	0%	25%	6%	0%	21%	9%
US06 City	8%	0%	0%	11%	0%	0%
US06 Hwy	0%	75%	26%	0%	79%	48%
Adjusted R-Squared	0.6927	0.8649	0.6034	N/A	N/A	N/A

A number of conclusions can be drawn from Table III.A-19. First, as might be expected, the two higher speed cycles are absent from the MOVES description of city driving; vice versa for highway driving. Second, the relative weighting for Bags 2 and 3 of the FTP in the description of city driving are similar, but not identical to those inherent in the FTP. Third, FTP driving is indicative of the great majority of the MOVES representation of city driving, nearly 90%. Fourth, the modeling indicates a strong preference to split the low and high speed driving of US06 into city and highway driving, respectively. In contrast, HFET driving is only indicative of 21% of the MOVES representation of highway driving. Even more interesting is the fact that the percentage of average U.S. driving as a whole which is represented by the HFET is only 9%. Based on the results shown in Table III.A-19, the HFET is the least representative and presumably contributes the least amount of predictive information regarding onroad fuel economy, of the three complete cycles. Of the individual bags, the US06 city bag is the least representative of driving overall. However, separating this low speed aggressive driving out of US06 appears to help focus the contribution of high speed, aggressive driving over the highway and overall, given the large contributions assigned to the US06 highway bag.

Because VSP is defined on a second by second basis, the VSP distributions used in the above regression analyses are on a time basis, not a mileage basis. For example, 60% of the time spent city driving is like that of Bag 2 of the FTP. However, because this Bag’s driving is the slowest of all the cycles, only 48% of the mileage spent city driving is like Bag 2. Since fuel economy is most commonly reported on a mileage basis, and not on a time basis, it is useful to convert the cycle combinations shown in Table III.A-19 above to a mileage basis. This is done by multiplying the percentages shown in Table III.A-19 by the average speed of the dynamometer cycle or bag presented in Table III.A-15 above.

The changes in the cycle weights for city and highway are relatively small, because the average speed of the cycles which predominate the city and highway weights all have similar (e.g., either low or high) speeds. Most of the percentages on a time basis change significantly when converted to a mileage basis for all U.S. driving, as every cycle other than US06 city has either much lower or much higher average speed than the overall U.S. average.

In their comments, Honda expressed concern over the high percentage of highway driving represented by the US06 highway bag given their impression of the extreme nature of the US06 highway driving cycle. As discussed in detail in the Response to Comments document, we used second by second fuel economy values of 80 vehicles tested over the FTP and US06 tests to estimate fuel economy over the HFET, US06 highway and onroad highway driving per the Draft MOVES2004 model. We found that the 5-cycle 79%/21% weighting of the US06 and HFET fuel consumption values predicted onroad highway fuel consumption much more accurately on an individual vehicle basis than the HFET fuel consumption alone (analogous to the current highway label formula). Thus, Honda's concern does not appear to be a real problem with the 5-cycle formulae.

Practically, the fuel economies of the various cycles or bags are combined harmonically, as is done today with the combination of city and highway fuel economies to estimate the 55/45 composite fuel economy. Mathematically, the formulae for running fuel use without consideration of air conditioning or cold temperature are:

<u>City Driving:</u>

$$RunningFC = \left(\frac{0.48}{Bag2_{75}\,FE}\right) + \left(\frac{0.41}{Bag3_{75}\,FE}\right) + \left(\frac{0.11}{US06\,City\,FE}\right)$$

<u>Highway Driving:</u>

$$RunningFC = \left(\frac{0.21}{HFET\ FE}\right) + \left(\frac{0.79}{US06\,Highway\,FE}\right)$$

<u>All U.S. Driving:</u>

$$RunningFC = \left(\frac{0.24}{Bag3_{75}\,FE}\right) + \left(\frac{0.19}{Bag2_{75}\,FE}\right) + \left(\frac{0.09}{HFET\ FE}\right) + \left(\frac{0.48}{US06\,Highway\,FE}\right)$$

For the NPRM, we developed a number of alternatives to these combinations. These alternatives were developed using: 1) different estimates of fuel consumption as a function of VSP, 2) whole cycles instead of bags, 3) a different split of the US06 test into city and highway portions, etc. We received very little comment on these alternatives. No new vehicle activity data has become available since the NPRM. Thus, we are retaining the cycle combinations shown in Table III.A-19 in the final 5-cycle formulae.

Hybrid vehicles are required to be tested over a full 4-bag FTP. Some manufacturers prefer to perform this test as a two bag test, with Bags 1 and 2 being combined into a single bag and Bags 3 and 4 being similarly combined. We developed cycle weighting factors for this case using the same methodology as described in Section III.A.2 of the Draft Technical Support Document to the NPRM. The result was a weighting factor of 0.90 for Bag 2 of a 2-Bag FTP and 0.10 for the US06 City Bag. These factors are only slightly different from a simple combination of the weighting factors for Bags 2 and 3 of the FTP (i.e., 89%) and US06 city shown in Table III.A-19 above.

Practically, the fuel economies of the various cycles or bags are combined harmonically, as is done today with the combination of city and highway fuel economies to estimate the 55/45 composite fuel economy. Mathematically, the formulae for running fuel use without consideration of air conditioning or cold temperature are:

<u>City Driving:</u>

$$RunningFC = \left(\frac{0.48}{Bag2_{75}\,FE}\right) + \left(\frac{0.41}{Bag3_{75}\,FE}\right) + \left(\frac{0.11}{US06\,City\,FE}\right)$$

<u>Highway Driving:</u>

$$RunningFC = \left(\frac{0.21}{HFET\,FE}\right) + \left(\frac{0.79}{US06\,Highway\,FE}\right)$$

For hybrids tested over a four bag FTP, the fuel consumption measured over Bag 4 can be substituted for Bag 2 in the city driving equation. The equation for hybrids tested over a two bag FTP is as follows:

<u>City Driving (Two-Bag FTP):</u>

$$RunningFC = \left(\frac{0.90}{Bag2_{75}\,FE}\right) + \left(\frac{0.10}{US06\,City\,FE}\right)$$

3. Effect of Air Conditioning on Fuel Economy

The performance of emission controls while the air conditioning system is operating is assessed via the SC03 test. The SC03 test begins with a hot start (i.e., the engine has been turned off for 10 minutes after having been fully warmed up prior to engine shutdown). The test cell is at 95°F and 40% relative humidity, with a solar load of 850 Watts per square meter on the vehicle. The vehicle is also pre-heated at this solar load for 10 minutes prior to the test, so the air conditioning compressor is generally engaged throughout the entire test. The driving pattern of the SC03 test is designed to represent driving performed immediately after vehicle start-up, so it is a relatively low speed cycle.[21,22] The driving pattern contained in the SC03 test is similar to that of the FTP, but not identical.

We estimate the impact of air conditioning operation on fuel economy based on the difference in fuel use over the SC03 and Bags 2 and 3 of the FTP. The most significant difference between these two tests from the perspective of fuel economy is the operation of the air conditioning system. However, differences in the driving pattern between the two tests should also be considered. Also, the air conditioning system is not always on in-use, so this needs to be accounted for. In addition, when the air conditioning system is on in-use, the temperature and relative humidity are not always 95°F and 40%, respectively. Temperature, in particular, can affect the load applied by the compressor on the engine. Thus, the effect of different ambient conditions should be considered, as well. Finally, the air conditioning compressor can also be engaged when the defroster is turned on. Each of these factors will be assessed below, starting with the difference in driving pattern.

Using the same methodology for modeling fuel use described above, we determined the combination of Bags 2 and 3 of the FTP and the US06 city cycle which matches the fuel use over the SC03 cycle with the air conditioning turned off. The adjusted r-squared value was higher without the US06 city bag than with it included. Therefore, we excluded this cycle from the final cycle combination. Overall, a combination of 39% of Bag 2 and 61% of Bag 3 on a mileage basis best represents the speed and power distribution of SC03. Thus, we propose to estimate the incremental fuel use due to the operation of the air conditioner at 95°F and 40% relative humidity at an average speed of 21.5 mph as the difference in fuel consumption measured over the SC03 versus this combination of fuel consumption over Bags 2 and 3 of the standard FTP. The following equation depicts this mathematically:

$$\textit{Excess fuel use due to air conditioning at } 95F =$$

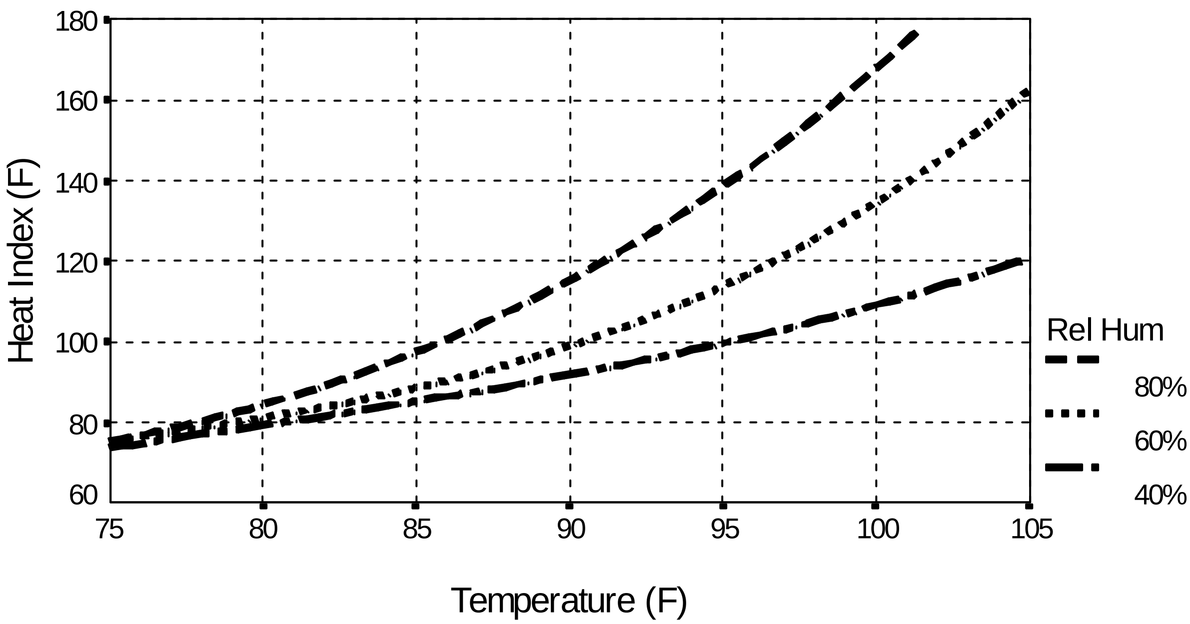
$$\left[\frac{1}{(\textit{Fuel economy over the SC03 test})} - \frac{1}{\left(\frac{0.39}{(\textit{FueleconomyoverBag}\,2)}\right)+\left(\frac{0.61}{(\textit{Fuel economy over Bag}\,3)}\right)}\right]$$

The next factor to address is that of compressor operation. The length of the SC03 test is 10 minutes. Since the vehicle has been sitting at 95°F for some time and has been under a solar load of 850 Watts per square meter for 10 minutes, the air conditioning compressor is usually engaged throughout the test. We assume here that the air conditioning compressor is engaged during 100% of the SC03 test. However, this estimate could be too high. The effect of a lower estimate will be evaluated in section III.E below.

This is not the case in-use. The air conditioning compressor generally cycles on and off depending on the ambient temperature, humidity, solar load and the length of time that the vehicle has been operating. The greater the temperature and humidity, the more often drivers turn the air conditioning on. The greater the temperature and humidity, the more frequent the compressor needs to operate in order to keep the cabin at a comfortable temperature; the shorter the trip, the more relevant any solar loading of the vehicle. Thus, it is appropriate to adjust the excess fuel use determined from the SC03 test to account for the times when the air conditioning compressor is not engaged.

The Draft MOVES2004 model contains an algorithm which estimates the percentage of time which the compressor is engaged as a function of heat index. Heat index is a complex combination of ambient temperature and humidity which was developed to predict degrees of personal comfort.[23] Heat index is used by the National Weather Service to quantify discomfort caused by the combined effects of temperature and relative humidity. Figure III-5 is reproduced from the MOBILE6 report and shows how heat index varies with both temperature and humidity.

Figure III-5. Heat Index vs. Temperature and Humidity



Note: Heat Index values based on shady conditions

Lines represent curve fit of tabular data

The Draft MOVES2004 algorithm of compressor on fraction versus heat index was developed from the direct measurement of air conditioning operation of over 1000 trips by 20 vehicles in Phoenix, Arizona during the summer and fall of 1992.[24] The algorithm considers both the frequency that the system is turned on by the driver and the frequency that the compressor is engaged once the system is turned on. The algorithm is of the form:

$$A/C\,compressor\,on\;fraction = A + B \times HeatIndex + C \times HeatIndex^2$$

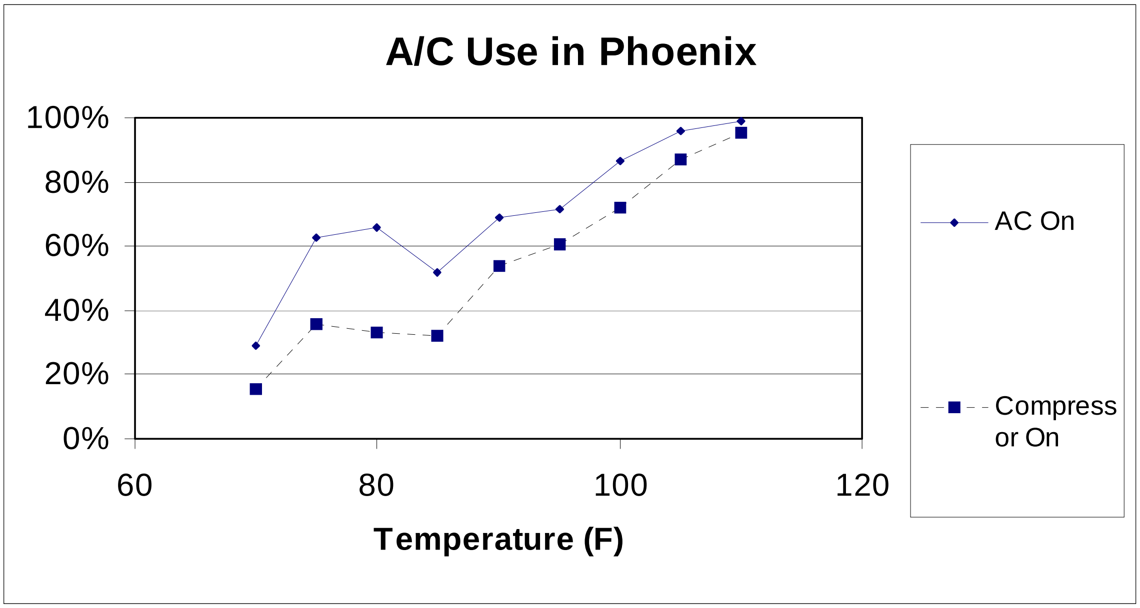
The coefficients vary depending on time of day, basically causing the predicted compressor use to increase when the sun rises higher in the sky for a given level of heat index. The coefficients are shown in Table III.A-20 below.

Table III.A-20. Coefficients for A/C Compressor Usage Equations

Heat Index	7-10 am, 5-9 pm			11 am - 4 pm			10 pm - 6 am		
	A	B	C	A	B	C	A	B	C
≤65	0	0	0	0	0	0	0	0	0
65-74	-4.101	0.0864	-0.000367	-4.101	0.0864	-0.00037	0.000	0.0000	0.000000
74-76	-2.930	0.0591	-0.000213	-4.101	0.0864	-0.00037	-1.257	0.0068	0.000143
76-96	-2.930	0.0591	-0.000213	-5.307	0.1140	-0.00052	-1.257	0.0068	0.000143
96-101	-3.632	0.0725	-0.000276	-5.307	0.1140	-0.00052	-1.257	0.0068	0.000143
101-104	-3.632	0.0725	-0.000276	-5.307	0.1140	-0.00052	-3.632	0.0725	-0.000276
104-110	-3.632	0.0725	-0.000276	-3.632	0.0725	-0.00028	-3.632	0.0725	-0.000276
>110	A/C compressor is engaged 100% of the time								

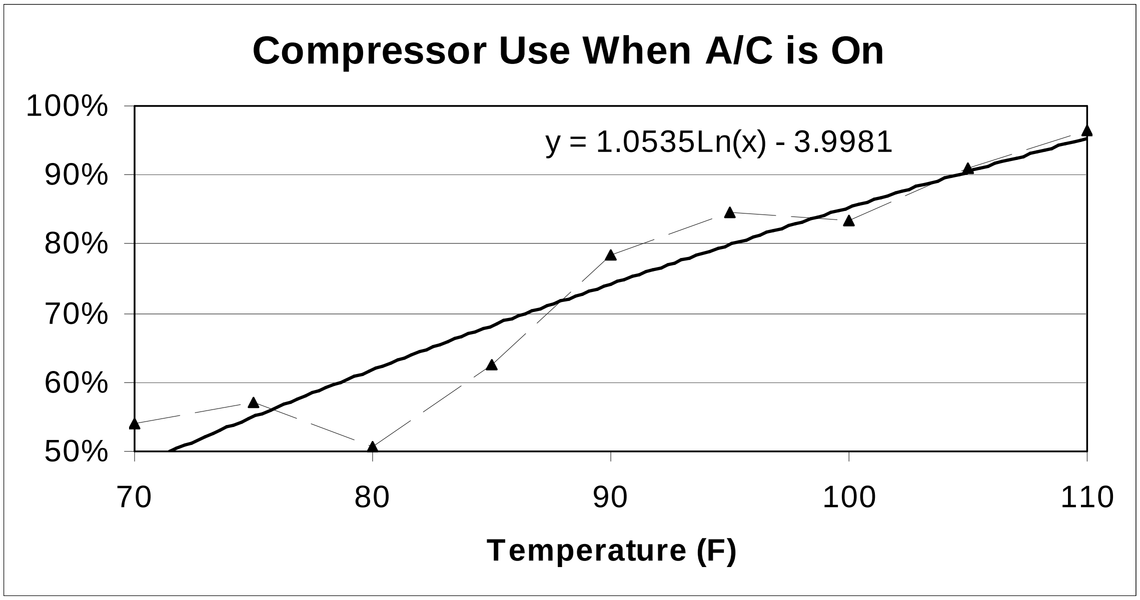
Since emissions and fuel economy are affected by the operation of the air conditioning compressor and not simply whether the switch is turned on or off, the MOBILE6 analysis did not develop analogous correlations for drivers turning their air conditioning systems on as a function of heat index. However, whether the switch was turned on or off was recorded during the test program. In order to provide a point of comparison with other studies, which have focused on the frequency that the switch is turned on, we estimated this parameter, as well. Using the data collected during the 1992 study in Phoenix,[25] we performed a regression of the average percentage of time during each trip that the A/C system was turned on against the ambient temperature at the time of the trip. For 5 degree F intervals, we calculated the average percentage of time that the air conditioning system was turned on and that the air conditioning compressor was engaged. These data are plotted in Figure III-6.

Figure III-6. Air Conditioning Use in Phoenix



We then calculated the ratio of the percentage of time that the compressor was engaged to the percentage of time that the air conditioning system was turned during each temperature interval. This ratio is essentially the percentage of time that the compressor was engaged while the system was turned on. These ratios are plotted in Figure III-7.

Figure III-7. Compressor Engagement as a Function of Ambient Temperature



We then performed a simple regression of these percentages as a function of temperature. The result was:

$$\text{Compressor engagement (fraction)} = 1.0535 \ln(\text{ambient temperature (F)}) - 3.9981$$

We then divided the MOBILE6 estimate of compressor on fraction by this estimate in order to convert the fraction of time that the compressor is on to the fraction of time that the air conditioning system is on.

We combined the estimates of air conditioning system on and compressor on fractions with 30-year average meteorological conditions for each hour of the day for every month of the year for each county in the U.S. to estimate the percentage of driving time during which the system and compressor were engaged under those conditions. We then weighted these percentages by the relative driving time occurring during each hour of the day and month in each county to obtain an estimate of the overall percentage of the time which air conditioning compressors are engaged in the U.S. From this, we estimate that, on average across the nation and throughout the year, the air conditioning system is turned on 23.9% of the time and the compressor is engaged 15.2% of the time.

We then adjusted this latter percentage to account for reduced compressor loads at temperatures less than 95°F and higher loads above 95°F.[26] Ed Nam, at the University of Michigan, developed a model of air conditioning load on the engine as a function of temperature.[27] From Figure 4 of this paper, we derived the following equation of compressor torque in foot-pounds versus temperature in degrees F.

$$\text{Compressor torque} = 1.70 + 0.084 * \text{Ambient Temperature (°F)}$$

At the temperature of the SC03 test, 95°F, compressor torque is 9.68 foot-pounds. Therefore, the estimated torque at a specific ambient temperature was divided by 9.68 and multiplied by the estimated compressor on fraction from Draft MOVES2004 in order to derive a compressor on fraction which was consistent with the conditions of the SC03 test. This adjusted formula for compressor on fraction was again applied to each county in the U.S., accounting for diurnal and seasonal temperature and driving differences. Adjusting for load, the compressor is on in-use 13.3% of the time, versus 15.2% without adjustment for load. Thus, the average load in-use is 87.5% of the load experienced during the SC03 test at 95°F.

Finally, the impact of air conditioning on fuel economy varies with vehicle driving pattern. Most air conditioning compressors are belt-driven by the engine. The efficiency of both the engine and compressor will vary with engine speed and load. This variation is difficult to model, as the speed and load of engines in various vehicles will vary dramatically based on the vehicle's drivetrain design, even over the same driving cycle. Lacking specific information on each vehicle's air conditioning system design and how engine speed and load affect it efficiency, we assume that the efficiency of the engine and air conditioning compressor implied in the SC03 test applies to other types of driving, as well. However, a more basic effect related to driving pattern is that the faster a vehicle is moving, the shorter the amount of time that the vehicle needs to be cooled while it travels a specific distance. Other factors being equal, this reduces the amount of energy needed to cool the vehicle per mile of travel. Therefore, for a specific set of ambient conditions, we assume that the impact of air conditioning on fuel use is constant with driving time (i.e., fuel use in terms of gallons per hour is constant). This means that the excess fuel use due to operating the air conditioner varies inversely proportional to vehicle speed. In other words, at low vehicle speeds, like that of the SC03 test, excess fuel use is relatively high on a per mile basis. At high vehicle speeds, like that of highway driving, the excess fuel use due to operating the air condition is relatively low on a per mile basis.

We confirmed this assumption by testing five vehicles over a variety of test cycles at EPA's Ann Arbor laboratory with both the air conditioning turned on and off. These tests were not run in an environmental chamber which simulates numerous aspects of higher temperature conditions, like humidity and solar load. Vehicles were tested as they normally required for an FTP at 75°F, except that the ambient temperature of the test cell was either higher or lower. Since the primary purpose of the test program was to determine the relative load of the compressor on the engine and the relative effect on fuel economy, this simplified test procedure was sufficient. A full report of this test program is contained in the docket.[28] The data are summarized in Table III.A-21.

Table III.A-21. Increased Fuel Use Due to Air Conditioning as a Function of Vehicle Speed

	60°F	75°F	95°F
Absolute increase in fuel consumption (gallons per 100 miles)			
FTP Bag 3	0.46	0.81	1.01
FTP Bag 2	0.70	1.11	1.41
HFET	0.27	0.41	0.50
SC03	----	0.87	----
Absolute increase in fuel consumption adjusted to 21.5 mph (gallons per 100 miles)			
FTP Bag 3	0.55	0.97	1.20
FTP Bag 2	0.52	0.83	1.06
HFET	0.60	0.91	1.13
SC03	----	0.87	----

The upper half of Table III.A-21 shows the increased fuel use as directly measured over the four cycles. The lower half multiplies these fuel increases by the ratio of the average speed of SC03 to the average speed of the cycle tested. As can be seen in the upper half of the table, the increase in fuel use varies by roughly a factor of three across the 3-4 cycles at each ambient temperature. The cycle with the highest vehicle speed, HFET, showed the smallest increase at all three temperatures. Bag 2 of the FTP, with the lowest average speed, showed the largest increase at all three temperatures. The fuel increases shown in the lower half of Table III.A-21 show much lower variability. Fuel increases now vary by less than 20% from lowest to highest at any given temperature. These data convincingly confirm the assumption that the increased fuel needed to operate the air conditioning system is roughly constant with time, as opposed to mileage.

Third, the air conditioning compressor also can be engaged in defroster mode to dehumidify the air and keep the windshield from fogging up. Due to the fact that the defroster tends to be operated at lower ambient temperatures than the air conditioner, the load on the engine is generally lower. We do not have a direct estimate of the frequency that the defroster is turned on, nor the frequency that the compressor is engaged during defroster mode. No study analogous to that performed in Phoenix has yet been performed. However, a recent study by the National Renewable Energy Laboratory (NREL) and the Office of Atmospheric Programs (OAP) within EPA estimated the percentage of time that people turned on the defroster, as well as the air conditioning system, while driving.[29,30]

This study uses a personal comfort model to predict when a driver would be likely to turn on the air conditioner. The greater the combination of ambient temperature and humidity, the more uncomfortably hot a person would feel. The more the model predicted that a person would feel uncomfortably hot, the greater the estimated likelihood that the driver would turn on the air conditioner. A simpler model was used for defroster use. If the ambient temperature is between 35 and 55°F and the relative humidity is greater than 80%, then the driver is assumed to turn on the defroster.

The NREL-OAP studies presented estimates of air conditioning use and air conditioning use plus defroster use by state, but not for the nation as a whole. We combined these state-specific estimates with the VMT estimates described above (aggregated by state) in order to estimate national averages. In the NPRM, we estimated that the national average air conditioning use was 22.9% and combined air conditioning plus defroster use was 33.5%. However, comments provided by NREL indicate that their more recent estimates of air conditioning and air conditioning plus defroster use are 28.1% and 32.6%, respectively. Since the conditions for air conditioning and defroster use do not overlap, national average defroster use, according to this model is 4.5% (versus the 10.6% figure estimated in the NPRM). Thus, the NREL-OAP model estimates slightly higher average air conditioning use nationwide (28.1%) than MOBILE6.2 (23.9%). These two estimates are still remarkably close given the differences in methodology. It is also not surprising that the MOBILE6.2 estimate would be the lower of the two, given that the NREL-OAP model does not account for people choosing alternatives to air conditioning use under hot-humid conditions, such as putting a convertible top down, driving with the windows open, or inoperative air conditioning systems.

The NREL-OAP study also performed vehicle modeling in order to estimate the impact of air conditioning and defroster load on vehicle fuel economy. They assumed an average temperature of 81°F for air conditioning use and 61°F for defroster use. (This defroster temperature exceeds the range of defroster use and appears to consider higher under the hood temperatures. However, the air conditioning temperature appears reasonable without such an adjustment.) The also used the FTP as their driving cycle. Assuming a mix of 65% cars and 35% trucks, the load of the air conditioner increased fuel consumption 19.8%, while that for the defroster was 4.1%. Thus, the impact of the defroster on fuel consumption is 20.7% of the impact of air conditioning. This includes the impact of a lower ambient temperature and the periodic cycling of the compressor on and off. NREL-OAP's modeling of the air conditioner is comparable to our estimate of 13.3% air conditioning use adjusted for compressor load. Thus, the 13.3% estimate can then be scaled based on the results of the NREL-OAP study.

Two scaling factors are necessary. One, defroster use is 13.8% of that air conditioning, based on the NREL-OAP results in both cases for consistency (4.5%/32.6%). (Use of our own estimate for air conditioning (23.9%) would increase this percentage by 36%, but we believe that it would be more appropriate to use estimates from the same source in this case.) Two, when turned on, defroster use has 20.7% of the fuel economy impact as air conditioning. Combining these two factors (20.7% times 13.8%) produces an overall scaling factor of 2.9%. Applying this to our estimate of 13.3% for the compressor on percentage in terms of the ambient conditions of the SC03 test produces an analogous estimate of 0.4% for defroster use. Combined air conditioning and defroster use would be 13.7% (13.3% + 0.4%), or 3% higher than that of air conditioning alone. This is a very small impact. We decided not to include the impact of defroster use in the 5-cycle formulae at this time for two reasons. One, no vehicle studies have yet been performed to confirm the projection that drivers actually turn on the defroster as assumed by NREL-OAP. Two, the ambient conditions existing during defroster use differ dramatically from those of the SC03 test.

Based on these three assumptions, the impact of air conditioning on running fuel use is estimated as 13.3% of the difference between fuel use per mile over the SC03 and a combination of Bag 2 and Bag 3 tests times 21.5 mph and divided by the average speed of either city or highway driving. Based on the descriptions of city and highway driving from Draft MOVES2004, the average speeds are 19.9 mph and 57.2 mph, respectively. Thus, the excess fuel use due to air conditioning operation is as follows.

For city driving:

Excess fuel use due to air conditioning =

$$0.133 \times \frac{21.5}{19.9} \times \left[\frac{1}{\left(\begin{matrix} Fuel\ economy \\ over\ the\ SC03\ test \end{matrix}\right)} - \frac{1}{\left(\frac{0.39}{\left(\begin{matrix} Fuel\ economy \\ over\ Bag\ 2 \end{matrix}\right)}\right) + \left(\frac{0.61}{\left(\begin{matrix} Fuel\ economy \\ over\ Bag\ 3 \end{matrix}\right)}\right)} \right]$$

For highway driving:

Excess fuel use due to air conditioning =

$$0.133 \times \frac{21.5}{57.2} \times \left[\frac{1}{\begin{pmatrix} Fuel\ economy \\ over\ the\ SC03\ test \end{pmatrix}} - \frac{1}{\left(\frac{0.39}{\begin{pmatrix} Fuel\ economy \\ over\ Bag\ 2 \end{pmatrix}} \right) + \left(\frac{0.61}{\begin{pmatrix} Fuel\ economy \\ over\ Bag\ 3 \end{pmatrix}} \right)} \right]$$

We received several other comments on this methodology. However, as discussed in the Response to Comments document, these comments did not lead us to revise the above equations. Thus, the 5-cycle formulae will continue to use the above relationships to estimate the impact of air conditioning use on city and highway fuel economy.

4. Effect of Cold Ambient Temperatures on Running Fuel Use

Finally, we added the impact of colder ambient temperatures on running fuel use. As was done for start fuel use, we base our estimate of the impact of colder ambient temperatures on running fuel use by comparing the fuel use over the standard and cold temperature FTP tests. At 75°F, engine, drivetrain and tires are generally assumed to be fully warmed up by the end of Bag 1. Thus, Bag 2 of the FTP at 75°F includes only fully warmed up operation. As was discussed above, the start fuel use associated with a 10 minute soak at 75°F is very small and generally considered to be negligible. Thus, Bag 3 at 75°F can also be considered to consist of essentially fully warmed up vehicle operation.

As discussed in detail in the Draft Technical Support Document to the NPRM, it is not clear that vehicles are fully warmed up during Bags 2 and 3 at 20°F. However, as described above, the average city driving trip is only 4.1 miles, well below that of the FTP (7.5 miles). Thus, Bags 2 and 3 of the cold FTP provide a reasonable estimate of warmed up driving during city-like driving (i.e., the vehicle is warmed up to the extent that it typically reaches during short trips). The effect of cold temperature on fuel use during city driving can be estimated from the difference in fuel use over Bags 2 and 3 of the FTP at 20°F and that at 75°F.

However, we could not make the same conclusion for either longer highway-like driving trips, nor conclude that the effect of colder temperatures would be the same at higher vehicle speeds. Based on a number of studies which investigated the impact of colder temperatures on fuel economy, we estimated that running fuel use at 20°F at higher vehicle speeds would be roughly 4% higher than that at 75°F.

When we determined the appropriate weighting factors for running fuel use at 20°F and 75°F in the NPRM, we assumed that running fuel use increased linearly with temperature below 75°F. We received one comment which challenged this assumption. As discussed in Section

5.2.4 of the Response to Comment document, we evaluated the running fuel use over Bags 2 and 3 of the FTP of several conventional Honda vehicles at 20, 50 and 75°F to determine if running fuel use did in fact change linearly with a decrease in temperature from 75°F. These data are summarized in Table III.A-22.

Table III.A-22. Warmed Up Fuel Use Versus Temperature: Honda Data			
	Bag 2 mpg	Bag 3 mpg	Bag 2+3 Fuel Consumption (gal/mi)
	75°F		
Civic	38.1	41.9	0.0251
Element	23.2	25.3	0.0414
Accord (L4)	25.6	30.0	0.0363
Accord (V6)	21.7	26.1	0.0424
MDX	17.2	20.2	0.0540
TSX	23.0	27.4	0.0401
Odyssey	20.9	24.5	0.0445
RSX PRB	24.0	28.5	0.0386
Average			0.0403
	50°F		
Civic	35.3	39.1	0.0270
Element	22.2	24.6	0.0429
Accord (L4)	23.4	28.4	0.0391
Accord (V6)	20.8	26.1	0.0434
MDX	16.8	20.3	0.0546
TSX	22.2	26.6	0.0415
Odyssey	19.1	22.6	0.0485
RSX PRB	22.7	28	0.0401
Average			0.0421
	20°F		
Civic	29.2	33.9	0.0320
Element	19.2	21.5	0.0494
Accord (L4)	20.6	25.2	0.0443
Accord (V6)	19.2	23.7	0.0473
MDX	15.2	17.9	0.0610
TSX	20.1	24.6	0.0454
Odyssey	17.5	21.4	0.0522
RSX PRB	20.7	25.3	0.0441
Average			0.0470

These data indicate that running fuel use at 50°F averaged 0.0421 gallon per mile, or 0.0018 gallon per mile higher than that at 75°F. Running fuel use at 20°F averaged 0.0470 gallon per mile, or 0.0067 gallon per mile higher than that at 75°F. Thus, fuel use increased faster below 50°F than from 75 to 50°F. On average the increase in running fuel use at 50°F was 27% that at

20°F. The same relationship was true when four hybrids (two Honda vehicles and two Toyota vehicles) were added to the database.

We used this relationship to evaluate the impact of ambient temperature on running fuel use throughout the U.S. using the same methodology that was used in conjunction with the assumption of linearity performed for the NPRM. The result was a weighting factor for running fuel use at 20°F of 0.18, versus the weighting factor of 0.30 developed for the NPRM. Thus, we have reduced the weighting factor for running fuel use at 20°F in the 5-cycle formulae for both city and highway fuel economy to 0.18. This is shown in the equations below.

For city driving:

$$\textit{Excess fuel use due to colder temperatures} =$$

$$0.18 \times \left[\left(\frac{0.5}{Bag\,2_{\,20}\,FE} + \frac{0.5}{Bag\,3_{\,20}\,FE} \right) - \left(\frac{0.41}{Bag3_{75}\,FE} + \frac{0.48}{Bag2_{75}\,FE} + \frac{0.11}{US06\,City\,FE} \right) \right]$$

For highway driving:

$$\textit{Excess fuel use due to colder temperatures} =$$

$$0.18 \times 0.04 \times \textit{running fuel use without air conditioning at } 75F =$$

$$0.18 \times 0.04 \times \left[\frac{0.21}{HFET\,FE} + \frac{0.79}{US06\,Highway\,FE} \right]$$

Combining the estimates of running fuel use at 75°F with the air conditioning turned off with the estimate of excess fuel use of running the air conditioning system and the estimate of fuel use due to colder ambient temperatures produces the following formulae for running fuel use:

For city driving:

$$Running\ Fuel\ Use =$$

$$0.82 \times \left[\frac{0.48}{Bag\,2_{75}\,FE} + \frac{0.41}{Bag\,3_{75}\,FE} + \frac{0.11}{US06\,City\ FE} \right] + 0.18 \times \left[\frac{0.5}{Bag\,2_{20}\,FE} + \frac{0.5}{Bag\,3_{20}\,FE} \right]$$

$$+ 0.133 \times 1.083 \times \left[\frac{1}{SC03\,FE} - \left(\frac{0.61}{Bag\,3_{75}\,FE} + \frac{0.39}{Bag\,2_{75}\,FE} \right) \right]$$

For highway driving:

$$Running\ Fuel\ Use =$$

$$(1.007) \times \left[\frac{0.79}{US06\,Highway\ FE} + \frac{0.21}{HFET\ FE} \right] + 0.133 \times 0.377 \times \left[\frac{1}{SC03\,FE} - \left(\frac{0.61}{Bag\,3_{75}\,FE} + \frac{0.39}{Bag\,2_{75}\,FE} \right) \right]$$

5. Adjustment Factor for Non-Dynamometer Effects

There are a large number of factors which affect vehicle fuel economy which are not addressed by any of the five current dynamometers tests. These include roadway roughness, road grade (hills), large vehicle loads (e.g., trailers, cargo, multiple passengers), wind, precipitation, to name just a few. Even when a factor is addressed by a dynamometer test, such as driving pattern or air conditioning, the factor is only approximately measured, as all realistic driving patterns cannot possibly be included in a test having a reasonable length of time. Nor can all the possible ambient conditions affecting air conditioner operation be tested. Thus, any estimate of in-use fuel economy derived from the five dynamometer tests is necessarily approximate.

It would be possible to use the formulae described in Section III.B to directly estimate the fuel economy label values. These fuel economy values would provide drivers with an indication of the relative fuel economy which they should expect to achieve in-use, at least the best estimate that the current five dynamometer tests can provide. This would provide vehicle purchasers with information as to which vehicle would provide greater or lesser fuel economy than another vehicle. However, as discussed in section I, many vehicle owners expect to achieve the fuel economy label values when they drive. Often, they do this to determine if their vehicle is operating properly. Thus, it would be advantageous to such vehicle operators if the fuel economy label values accounted for all factors affecting fuel economy and not just those addressed by the dynamometer tests. This is the rationale for the 90% and 78% adjustment factors which are currently applied to the measured FTP and HFET fuel economies when determining the city and highway label values. This cannot be done in a vehicle specific manner, since no such estimates are available without additional dynamometer tests and additional vehicle testing. However, it is possible to account for these factors on a fleet wide basis, as was done with the current 90 and 78% adjustment factors.

It is possible to estimate the effect of each of the untested factors mentioned above and then add them up. This was done as part of the 1984 label adjustment rule. That study estimated that the net effect of all the non-dynamometer factors was roughly 30%.[31] However, at that time, these factors included the impact of vehicle speed, acceleration, colder temperature and air conditioning, in addition to the factors described above. With the inclusion of the fuel consumption over the US06, SC03 and cold FTP tests in the 5-cycle formulae, the net effect of these factors should be much smaller. One caution is that the comparisons of dynamometer measured fuel economy and onroad fuel economy performed for the 1984 rule tended to find a smaller shortfall than the total of all the individual non-dynamometer factors. The reason for this was not clear. In other words, the individual factors which might have been over-estimated could not be determined. In this section, we will update the impact of several of these factors and develop a revised estimate of the overall impact of non-dynamometer factors on onroad fuel economy relative to an estimate based on the 5-cycle formulae.

The easiest factor to quantify is likely that related to fuel energy density. EPA's test fuels do not contain any oxygen. However, commercial gasoline can contain either of two oxygenates, methyl tertiary butyl ether (MTBE) and ethanol. Future levels of MTBE use are uncertain because of water contamination issues related to leaking underground storage tanks. However, the recently passed Energy Policy Act of 2005 (EPA2005) guarantees a certain level of ethanol use. For example, in 2008, EPA2005 requires the use of 5.4 billion gallons of renewable fuel, the vast majority of which is expected to be ethanol blended into gasoline. DOE projects that total gasoline consumption will be 146 billion gallons in 2008. Thus, ethanol would represent 3.7% of gasoline by volume. Ethanol contains roughly 33% less energy per gallon, so on average, commercial gasoline in 2008 will contain 1.2% less energy per gallon than it would if it were not oxygenated. Engine efficiency is unaffected by fuel energy content in this range. Thus, reducing the energy content of gasoline by 1.2% will reduce volumetric fuel economy by the same 1.2%. This is not reflected in EPA dynamometer testing.

Currently, dynamometer testing performed for the state of California is done using a fuel containing 2% oxygen by weight. This fuel contains approximately 2% less energy per gallon than EPA's test fuel. In many cases, dynamometer tests performed for California can also be used in EPA certification. Thus, it would be appropriate to divide the measured fuel economy of any test performed using an oxygenated California test fuel by one minus the oxygen content of that fuel by weight, usually 2%. However, with the passage of EPA2005, gasoline sold in Federal reformulated gasoline areas in California will no longer be required to contain two weight percent oxygen. Thus, California may no longer require its test fuels to contain oxygen. In any case, measured fuel economy using an oxygenated fuel should be adjusted to reflect the energy content of EPA's non-oxygenated test fuel. At the same time, the average driver in 2008 will achieve 1.2% lower fuel economy than they would if they were using a non-oxygenated fuel.

The volume of renewable fuel required under EPA2005 increases in later years, reaching 7.5 billion gallons in 2012. Assuming this is all ethanol and using DOE's projected gasoline volume of 147 billion gallons, average commercial gasoline would contain 1.5% less energy than EPA test fuel. Thus, in the early years of the revised fuel economy labels, difference in fuel quality will cause onroad fuel economy to be 1.2-1.5% less than that measured on the dynamometer.

Another factor which has recently been studied in some detail is tire pressure. NHTSA recently promulgated a regulation requiring car and light truck manufacturers to install tire pressure monitoring systems in future vehicles. In preparation for this rule, NHTSA conducted a survey of the tire pressure of in-use vehicles in February 2001.[32] Tire pressures were measured on over 11,500 vehicles at 24 locations throughout the U.S. The results are summarized in the Table III.A-23. NHTSA presented data for each of the four tires separately (i.e., front, driver's side tire).[33] We averaged the findings for the four tires.

Table III.A-23. NHTSA Onroad Tire Pressure Survey

Difference between Onroad and Manufacturer's Recommend Tire Pressure (psi) (Average of four tires)	Cumulative Frequency	
	LDVs	LDTs
-12	3.0%	3.0%
-11	5.0%	6.0%
-10	7.5%	8.5%
-9	9.5%	11.0%
-8	12.0%	15.0%
-7	16.0%	20.0%
-6	20.0%	25.5%
-5	26.0%	34.5%
-4	31.5%	40.0%
-3	40.0%	47.0%
-2	46.5%	54.5%
-1	54.0%	62.0%
0	61.0%	69.0%
1	68.0%	75.0%
2	74.5%	80.0%
3	79.0%	84.0%
4	85.5%	88.0%
5	88.0%	91.0%
6	90.0%	92.0%
7	94.0%	93.0%
8	95.0%	95.0%
9	96.0%	97.0%
10	97.0%	98.0%
11	98.0%	99.0%
12	99.0%	100.0%

As can be seen from the table, 54-62% of cars and light trucks have under-inflated tires, while 31-39% have over-inflated tires. Using these estimates, we found that the tires of the average car were under-inflated by 1.1 psi, while those on light trucks were under-inflated by 1.9 psi.

NHTSA presented two estimates of the effect of tire pressure on fuel economy. A 1978 study by Aerospace Corp. found that fuel economy decreased by 1% for every 3.3 psi decrease in tire pressure, while more recent test data submitted by Goodyear showed a 1% decrease in fuel economy for every 2.96 psi decrease in tire pressure. Using these two factors, the 1.1 psi under-inflation of car tire pressure causes a 0.3-0.4% decrease in onroad fuel economy. The 1.9 psi under-inflation of light truck tire pressure causes a 0.6% decrease in onroad fuel economy. Assuming that new vehicles average close to their CAFE fuel economy standards (27.5 mpg for cars and 20.6 mpg for light trucks) and a 50/50 mix of the two types of vehicles, the fleet-wide effect of under-inflation is 0.5% using either factor.

NHTSA recently promulgated a regulation requiring manufacturers to monitor tire pressure.[34] This rule requires vehicles to be equipped with sensors to detect a tire which is under-inflated by 25% or more. With a few exceptions, the regulation begins phasing in with the 2006 model year and all new cars and light trucks must have the monitoring systems by the 2008 model year. Assuming a tire's recommended pressure is about 32 psi, this implies catching tires under-inflated by 8 psi or more. If we assume that the regulation is 100% effective and eliminate all tires under-inflated by 8 psi or more in Table III.A-23 above, passenger car tires are no longer under-inflated on average in-use; they exceed their specifications by roughly 0.1 psi. Light trucks are still under-inflated by about 0.4 psi. Across the light duty fleet, the net effect on fuel economy decreases to 0.1%, or roughly one-fifth the level prior to the rule. Of course, the effectiveness of the rule could be less than 100%. At the same time, vehicles with a single tire under-inflated by 8 psi could have other tires with a lower degree of under-inflation. Thus, the rule could have some effect on tires with smaller levels of under-inflation than assumed above. In any event, the effect should be less than 0.5% and could be close to zero.

A third factor which can be quantitatively estimated is the effect of wind. Wind affects fuel economy by changing the road load of the vehicle. Wind can affect both rolling resistance and aerodynamic drag. Rolling resistance is primarily affected by a side wind, which pushes the vehicle sideways. The driver must compensate by turning the steering wheel into the wind. This increases the drag caused by the tires on the roadway surface. However, the effect of wind on aerodynamic drag is far the larger of the two effects.

Aerodynamic drag is generally assumed to be the product of three factors: 1) the frontal area of the vehicle, 2) the air speed going by the vehicle squared, and 3) the "drag coefficient or C_d." A headwind increases the speed of the air going by the vehicle directly (i.e., a 10 mph wind increases air speed 10 mph). A tailwind decreases air speed by the vehicle. Even if the frequency of a headwind and a tailwind is the same, total aerodynamic drag increases, due to the fact that drag is proportional to air speed squared. For example, 40 mph squared is 1600 mph^2. Given a headwind of 10 mph, air speed increases to 50 mph and 50 mph squared is 2500 mph^2. Given a tailwind of 10 mph, air speed decreases to 30 mph and 30 mph squared is 900 mph^2. The average of 2500 and 900 mph^2 is 1700 mph, which is more than 6% greater than 1600 mph^2.

Thus, even a randomly directional wind will increase total aerodynamic drag and decrease fuel economy.

An even greater effect of wind, however, is that it changes the drag coefficient, C_d, and increases the effective frontal area of the vehicle in the direction of the wind. For example, as large as the frontal area is of a semi-tractor trailer combination, its area from a side view is 5-10 times as large. The greater the side wind relative to vehicle speed, the more the truck is actually driving sideways down the road as far as aerodynamic drag is concerned. With respect to cars and light trucks, their body shapes are designed to reduce aerodynamic drag when traveling into the wind. Front and rear ends are sloped. Spoilers and other rear end shapes are designed to minimize the creation of vortices behind the vehicle which "pull" the vehicle back as it is driving forward. However, as soon as a significant side wind occurs, these benefits start to diminish.

For the 1984 label adjustment rule, EPA estimated that wind reduced onroad fuel economy by 3% for a small car and 2% for a large car.[29,35] These estimates were based on several estimates made by the Department of Transportation: 1) the effect of 10, 15, and 20 mph winds on aerodynamic drag at a constant speed of 55 mph as a function of wind angle, 2) the effect of increased aerodynamic drag on 55 mph fuel economy, and 3) a distribution of onroad VMT as a function of wind speed (with the national average wind speed being 9 mph). EPA applied these estimates directly to highway fuel economy, but reduced the fuel economy effect by 80% for city driving. This reduction was based on the fact that roughly 20% of the FTP test is at speeds near 55 mph.

We reviewed this methodology in detail to determine if any improvement could be made. Two areas were identified. The first area was the fact that the effect was estimated only for cars, as that was the focus of the study. The second area was the assumption that wind had no effect on fuel economy at vehicle speeds below roughly 55 mph. While aerodynamic drag is much lower at city driving like speeds than highway speeds, wind speed is a higher fraction of vehicle speed at low vehicle speeds. The effect of wind on a vehicle's effective drag coefficient increases as the effective angle of the air speed increases. Thus, the effect of a side wind can be significant, even at low vehicle speeds.

In order to expand the previous analysis, we developed a model of aerodynamic drag and its impact on fuel economy as a function of wind speed and angle. We broke down the speed of the vehicle through the air in terms of its x and y coordinates (i.e., parallel and perpendicular to the direction of the vehicle). The parallel component is the speed of the vehicle plus the cosine of the wind angle times wind speed. The perpendicular component is the sine of the wind angle times wind speed. We then calculated the net angle of the air flowing past the vehicle and its speed from these two x-y components. The net angle of the air flowing past the vehicle is the arctangent of the ratio of perpendicular air speed to parallel air speed. Net air speed is the square root of the sum of the square of the perpendicular air speed and the square of the parallel air speed. Aerodynamic drag is the square of the net air speed times the vehicle drag coefficient.

DOT estimated that the vehicle drag coefficient increased 1.5% for every degree increase in yaw angle, or angle of net air flow past the vehicle. Using this estimate, we were able to reproduce the estimates of the change in aerodynamic drag as a function of wind speed and direction on a vehicle traveling at 55 mph, which were presented Figure 26 of the EPA report.[33]

In order to broaden the estimate to include light trucks, we obtained estimates of the effect of wind angle on a vehicle's drag coefficient from Gillespie.[36] Gillespie presents the estimated absolute increase in drag coefficient as a function of wind speed for four vehicle designs: pick-up trucks, station wagons, family sedans, and sports cars. The results are presented in Table III.A-24 below in tabular form. Gillespie did not present estimates for sport utility vehicles (SUV). We estimated the effect for SUVs by averaging the impacts for pick-up trucks and station wagons.

Table III.A-24. Effect of Wind Angle on Vehicle Drag Coefficient

Wind Angle (Deg)	Pick-Up Truck	Station Wagon	Family Sedan	Sports Car	SUV	Average
0	0	0	0	0	0	0
5	0.045	0.015	0.010	0.010	0.030	0.025
10	0.120	0.050	0.040	0.025	0.085	0.070
15	0.195	0.090	0.080	0.050	0.143	0.121
20	0.240	0.110	0.125	0.070	0.175	0.155

We estimated a fleet average change in the effective drag coefficient by averaging the estimates for the five model types. We averaged the estimates for the three types of passenger cars equally (33/33/33), the two estimates for light trucks equally (50/50) and then averaged the averages for car and light trucks equally (50.50). For a wind angle of 20 degrees, the average change in drag coefficient for cars is 0.102 and 0.208 for light trucks. Assuming average drag coefficients in still air of 0.30 for passenger cars and 0.40 for light trucks,[25] these changes represent increases of 1.7% and 2.6% per degree of wind angle. The figure for cars matches the DOE estimate from 1974 quite well, while that for light trucks is much larger. We performed a regression of the change in drag coefficient versus wind angle in degrees and found the following relationship:

$$\textit{Change in drag coefficient} = -0.00376 + 0.006815 \times \textit{wind angle} + 0.000065 \times (\textit{wind angle})^2$$

We also performed a similar regression used a linear model. The linear model yielded larger average increase in vehicle drag coefficient. Therefore, we retained the non-linear model.

In order to expand the estimate to include city, as well as highway driving, we again used PERE.[25] Using PERE, we estimate that a 10% increase in aerodynamic drag or drag coefficient decreases city fuel economy by 0.93%. Likewise, highway fuel economy decreases 3.11%. Implied in the DOT estimate of the effect of wind speed on 55 mph fuel economy is a decrease of roughly 4%. Thus, PERE estimates a somewhat lower effect of wind speed on fuel economy even at highway speeds.

We then applied our model using the DOT estimates of the national average distribution of wind speeds, which is shown in Table III.A-25 below. We assumed that the average wind speed within a range of wind speeds was the average of the lower and upper limit of the range. We assumed that the average wind speed for winds above 25 mph was 27.5 mph.

Table III.A-25. Frequency of Wind Speeds in the U.S.		
Wind Speed (mph)	Assumed Average Wind Speed (mph)	% of National VMT
0-3	1.5	16%
4-7	5.5	28%
8-12	10	30%
13-18	15.5	18%
19-24	21.5	6%
25	27.5	2%

Using an average vehicle speed of 19.9 mph for city driving and 57.1 mph for highway driving (from Draft MOVES2004), the vehicle drag coefficient increases by 73.5% and 15.9%, respectively, on average. Assuming average city and highway fuel economy of 18.8 and 25.5 mpg (from our database of 615 recent model year vehicles without any factor for non-dynamometer effects) and city and highway VMT weights of 43% and 57%, respectively, composite fuel economy is 22.1 mpg in still air and 20.8 mpg with a typical distribution of wind. Thus, taking wind into account reduces onroad fuel economy by 6%. This is more than twice that estimated for the 1984 label adjustment rule.

Roughly 60% of this 6% increase is due to the increase in drag coefficient during city driving. This portion of the estimate is likely the most uncertain, due to the large wind angles which can occur at relatively low vehicle speeds (e.g., 45% or more). This means that the figures taken from Gillespie are being extrapolated to a significant degree. We are not certain that the drag coefficient would continue to increase beyond 20 degrees wind angle at the same rate as below 20 degrees. However, the effective frontal area of the vehicle would continue to increase. Rolling resistance is also likely to increase, as the vehicle must be driven increasingly sideways to travel in the direction that the vehicle is pointing (i.e., down the road). It is unlikely that either the DOT or Gillespie estimates consider an increase in rolling resistance, as they were likely developed in wind tunnels where the vehicle is standing still. Thus, it is likely that the estimate for the effect of wind on onroad fuel economy is more uncertain than those for fuel quality or tire pressure. Still, the effect of wind appears to be very significant and likely larger than either of the other two factors.

The final factor which we reevaluated was road roughness. Road roughness was estimated to reduce onroad fuel economy by 4.2% relative to that measured on the dynamometer.[29] The model developed in 1980 included estimates of the percentage of VMT driven on dry (69%), wet (25%) and snow-covered (6%) roads.[33] It also included estimates of roadway miles which were unsurfaced, gravel, low-load asphalt, and concrete and high load asphalt. It also included estimates of the percentages of VMT on each roadway type, as well as the effect of each roadway type on fuel economy relative to that measured on a dynamometer. As the vehicle coast downs used to determine dynamometer road loads are conducted on dry concrete or high load asphalt roads, this combination of roadway type and driving condition was assumed to have no effect on fuel economy relative to a dynamometer. All other roadway types and driving conditions reduced onroad fuel economy. Table III.A-26 presents the inputs to the model developed in 1980 (with highway and VMT estimates from FHWA's Highway Statistics 1977).

Table III.A-26. Effect of Road Roughness on Onroad Fuel Economy: 1977				
	Unsurfaced	Gravel	Low-load Asphalt	Concrete or High-load Asphalt
Percent of Roadway Miles	18.2%	31.1%	27.3%	23.4%
Percent of VMT	1.8%	9.7%	30.2%	58.3%
Effect on Onroad Fuel Economy				
Dry	-20%	-15%	-4%	0%
Wet	-30%	-18%	-5%	-3%
Snowy	-35%	-20%	-10%	-7%

The net effect of the inputs shown in Table III.A-26 and the percentages of VMT with various road conditions cited above was an average fuel economy shortfall of 4.4%.

We updated the model using more recent estimates of VMT by roadway type contained in FHWA's Highway Statistics 2003. We had to combine estimates from a set of tables in order to estimate VMT by cars and light-duty trucks by roadway surface. We began with estimates of national VMT by cars and 2-axle, 4 tire trucks by roadway type in 2003 from Table VM-1. We then converted the VMT by 2-axle, 4 tire trucks to the VMT by EPA-defined light-duty trucks by multiplying by 0.9234, which was derived from an Oak Ridge National Laboratory study. According to this study, 7.66% of the VMT by 2-axle, 4 tire trucks is by trucks which have a curb weight above 6000 pounds or a gross vehicle weight rating of above 8500 pounds, which put these vehicles into EPA's heavy-duty vehicle class.

We then obtained estimates of the length of roadway by surface type for each roadway class from Table HM-12. The surface types used in Table HM-12 differ somewhat from those cited in the EPA fuel economy study and shown in Table III.A-26. Table HM-12 uses two major classes of roadway surface: Unpaved and Paved. There are five sub-classes of paved roadway surfaces: low, intermediate, high-flexible, high-composite, and high-rigid, where low, intermediate and high refer to the weight carrying capacity of the roadway. According to FHWA, Paved includes the following categories:

Low type-- an earth, gravel, or stone roadway which has a bituminous surface course less than 1" thick suitable for occasional heavy loads;
Intermediate Type-- a mixed bituminous or bituminous penetration roadway on a flexible base having a combined surface and base thickness of less than 7";
High-Type Flexible-- a mixed bituminous or bituminous penetration roadway on a flexible base having a combined surface and base thickness of 7" or more; also includes brick, block, or combination roadways;

High-Type Composite-- a mixed bituminous or bituminous penetration roadway of more than 1” compacted material on a rigid base with a combined surface and base thickness of 7” or more;

High-Type Rigid-- a Portland Cement Concrete roadway with or without a bituminous wearing surface of less than 1”.

From these definitions, it seemed that the gravel referred to in the definition of the Low Paved class was the support for the bituminous surface. This would imply that both unsurfaced and gravel surfaced roadways of Table III.A-26 fell into the unpaved categories. However, it also seemed possible that the gravel roadways referred to in Table III.A-26 were included in the low paved category. It also seemed uncertain whether the high, flexible paved roadway fell into the low-load asphalt or high-load asphalt. In order to reflect these uncertainties, we developed to mappings of these six roadway surfaces onto the four types used in the EPA study in order to bracket the potential fuel economy impact. Table III.A-27 shows these two mappings.

Table III.A-27. Mapping of Roadway Surfaces

	Unsurfaced	Gravel	Low-load Asphalt	Concrete or High-load Asphalt
Low Fuel Economy	Unpaved	Low Paved	Intermediate + High-Flexible Paved	High-Composite + High-Rigid Paved
High Fuel Economy	None	Unpaved + Low Paved	Intermediate Paved	High-Flexible + High-Composite + High-Rigid Paved

Using these two sets of roadway mappings, we converted the total roadway lengths for each roadway surface class within each highway class from Table HM-12 into lengths of roadway by the surface classes shown in Table III.A-26 within each highway class.

We then estimated the effect of roadway condition on the fuel economy of vehicles driving on each roadway surface type. We did this by multiplying the estimates of the percentage of VMT driven on dry (69%), wet (25%) and snow-covered (6%) roads to the changes in fuel economy for each roadway condition for each roadway surface (shown in Table III.A-26). The result is that the average fuel economy on unpaved roads, gravel roads, low load paved road and high load paved roads are 72.5%, 83.9%, 95.1%, and 98.8% of that on dry high load paved roads like those simulated during dynamometer testing.

We then applied these effects of roadway conditions to the distribution of roadway surfaces for each highway class in order to develop estimates of the average effect of roadway conditions for each highway class. We then weighted these effects by the distribution of car and light truck VMT by highway class in order to develop a national average effect of roadway surface and condition on fuel economy. Using the two mappings, we estimate that the national average impact of roadway surface and condition on fuel economy is 1.4-3.2%. Based on the decisions underlying the two mappings, we believe that the low end of this range is more likely than the high end. Thus, it appears that the effect of roadway surface and condition is lower today than it was in 1977.

The other non-dynamometer factors are more difficult to estimate. Fortunately, they appear to be smaller in magnitude. The following table shows the breakdown of the impact of all the non-dynamometer factors as estimated for the 1984 rule. It also updates the impacts for the four factors discussed above, as well as eliminating those factors which are now addressed by the US06, SC03 and cold FTP tests.

Table III.A-28. Effect of Non-Dynamometer Factors on Onroad Fuel Economy

Factor	Analysis for 1984 Rule	Effect Applicable to 5-Cycle Fuel Economy
Ambient temperature	-5.3%	Included
Fuel Quality	0%	-1.1 to -1.5%
Altitude	-0.1%	-0.1%
Wind	-2.3%	-6%
Road grade	-1.9%	-1.9%
Road surface	-4.2%	-1.4% to -3.2%
Road curvature	-0.1%	-0.1%
Trip length	0.8%	Included
Average vehicle speed	10.6%	Included
Cold starts	-0.7%	Included
Acceleration intensity	-11.8%	Included
Brake drag	-0.3%	-0.3%
Wheel alignment	-0.3%	-0.3%
Tire switching	-0.4%	-0.4%
Tire pressure	-3.3%	-0.5%
Vehicle load	-0.4%	-0.4%
Dynamometer loading	-2.7%	Revised test procedures may have removed most of these effects
Tire effects	-5.1%	
Weight classification	-1.0%	
Manual transmissions	-1.8%	
Power accessories, air conditioning	~0%	Air conditioning included
Sum	-30%	-12% to -15%

As can be seen, the net impact of non-dynamometer factors applicable to a 5-cycle fuel economy estimate is 12-15%. The four factors evaluated in detail above comprise the majority of the impact. Together, other factors like road grade, road curvature, altitude and vehicle condition add only 3.5% to the overall estimate.

We received little comment on the estimates of the impacts of the individual untested factors on onroad fuel economy. One commenter indicated that he thought that the effect of wind seemed high, but offered no specific information on how the methodology or estimate should be changed.

Due to the fact that this type of analysis seemed to over-estimate the impact of these factors compared to onroad fuel economy estimates from owner diaries, we performed a second analysis starting from fleet-wide fuel economy estimates.

As described above in section II.C above, FHWA develops annual estimates of car and light truck fuel economy based on estimates of total VMT and fuel consumption across the nation. For the NPRM, we utilized FHWA fuel economy estimates for the 2002 and 2003 vehicle fleets. Since the time of the NPRM, FHWA has updated their estimate of onroad fuel economy for the 2003 fleet and published an estimate for the 2004 fleet. These latest estimates show lower onroad fuel economy for light trucks than those estimated recently. After adjusting for the difference FHWA's and EPA's definition of light trucks, onroad fuel economy was 19.7 and 19.9 mpg in 2003 and 2004, respectively. Using MOBILE6.2, we estimate that fleetwide label fuel economy for these calendar years were 21.1 and 21.2 mpg, respectively. This indicates a current shortfall of roughly 6.5-7.0%.

Absent any non-dynamometer factor, the average combined (55/45) current label value for the 601 conventional vehicles in our certification fuel economy database is 20.9 mpg, while the average combined (43/57) 5-cycle fuel economy is 21.6 mpg, or 3.5% higher. Thus, the shortfall between the combined 5-cycle fuel economy and the FHWA-based fleet estimates is roughly 10-10.5%.

In the NPRM, we added one more factor to account for changes in FTP and HFET test procedures when EPA implemented the Supplemental FTP standards. Specifically, we reduced combined fuel economy by 3% to compensate for the removal of a 10% upward adjustment to the vehicle's tractive road load horsepower setting on the dynamometer. However, we received a comment that, at the time of the SFTP rule, EPA had found that the net fuel economy effect of all the changes in test procedures was zero, not 3%. We agree with this comment. Therefore, we have removed this 3% adjustment from this analysis. Thus, the shortfall between the combined 5-cycle fuel economy and the FHWA-based fleet estimates remains at roughly 10-10.5%.

This 10-10.5% difference is slightly lower than the 12-15% estimate for the impact of non-dynamometer factors shown in Table III.A-28. In the NPRM, we decided to average the two estimates, rounding down, and include a factor of 0.89 in the 5-cycle city and highway formulae (i.e., a reduction of 11% in both city and highway fuel economy) to account for the impact of these factors. As discussed above, however, the bottom-up approach over-estimated the net effect of these factors back in 1984 when the current label adjustments were developed. Thus, for the final 5-cycle formulae, we decided to place more emphasis on the top-down comparison. Therefore, we set the value of the non-dynamometer factor so that the fleetwide combined 5-cycle fuel economy matches onroad fuel economy as estimated by FHWA.

As indicated above, the average of the current combined fuel economy label values in our certification fuel economy database (20.9 mpg) is slightly lower than that for the entire onroad fleet (21.1-21.2 mpg per MOBILE6.2). Thus, the certification database appears to be biased low by 1.0-1.5% relative to the onroad fleet. Thus, the average of the combined 5.cycle fuel economy label values in our certification fuel economy database should also be 1.0-1.5% lower than the onroad fuel economy estimated by FHWA (19.7-19.9 mpg), or about 19.6 mpg. Incorporating a non-dynamometer factor of 0.905 into the 5-cycle city and highway formulae produces an average combined label value of 19.6 mpg. Thus, we have set the value of the non-dynamometer factor in the final 5-cycle formulae to 0.905.

6. 5-Cycle Fuel Economy Formulae

The complete 5-cycle fuel economy formulae are developed by combining the results of the sections on start fuel use, running fuel use, air conditioning, cold temperature, and non-dynamometer effects. The resultant formulae are described below.

Under the final rule, a special situation could exist where the city fuel economy of a model type could be developed using the mpg-based formula and its highway fuel economy developed using an alternative 5-cycle formula based on testing over only 3 test cycles (FTP, HFET, and US06). This alternative 5-cycle fuel economy formula is also described below.

a. 5-Cycle Fuel Economy Formulae

Vehicles Tested Over a Three-Bag FTP at 75 F

5-Cycle City Fuel Economy Formula

The final 5-cycle city fuel economy would be calculated as follows:

$$City\ FE = 0.905 \times \frac{1}{Start\ FC + Running\ FC}$$, where

$$StartFC\ (gallons\ per\ mile) = 0.33 \times \left(\frac{(0.76 \times StartFuel_{75}) + (0.24 \times StartFuel_{20})}{4.1} \right)$$,

where,

$$Start\ Fuel_x = 3.6 \times \left[\frac{1}{Bag\,1\,FE_x} - \frac{1}{Bag\,3\,FE_x} \right]$$, where

Bag y FE_x = the fuel economy in miles per gallon of fuel during Bag 1 or Bag 3 of the FTP test conducted at an ambient temperature of 75 or 20°F.

Running FC =

$$0.82\times\left[\frac{0.48}{Bag2_{75}\,FE}+\frac{0.41}{Bag3_{75}\,FE}+\frac{0.11}{US06\,City\,FE}\right]+0.18\times\left[\frac{0.5}{Bag2_{20}\,FE}+\frac{0.5}{Bag3_{20}\,FE}\right]$$

$$+\,0.133\times1.083\times\left[A/C\,FC\right]$$

where

$$A/C\,FC=\left[\frac{1}{SC03\,FE}-\left(\frac{0.61}{Bag3_{75}\,FE}+\frac{0.39}{Bag2_{75}\,FE}\right)\right]$$, where

US06 City FE = fuel economy in miles per gallon over the city portion of the US06 test,
US06 Highway FE = fuel economy in miles per gallon over the Highway portion of the US06 test,
HFET FE = fuel economy in miles per gallon over the HFET test,
SC03 FE = fuel economy in miles per gallon over the SC03 test.

5-Cycle Highway Fuel Economy Formula

The final 5-cycle highway fuel economy would be calculated as follows:

$$Highway\ FE=0.905\times\frac{1}{Start\ FC+Running\ FC}$$, where

$$StartFC\ (gallons\ per\ mile)=0.33\times\left(\frac{(0.76\times StartFuel_{75})+(0.24\times StartFuel_{20})}{60}\right),$$

where

$$Start\ Fuel_x=3.6\times\left[\frac{1}{Bag1\,FE_x}-\frac{1}{Bag\,3\,FE_x}\right]$$, and

$$Running\ FC=1.007\times\left[\frac{0.79}{US06\,Highway\,FE}+\frac{0.21}{HFET\ FE}\right]+0.133\times0.377\times\left[A/C\,FC\right]$$

where the various symbols have the same definitions as just described above.

Hybrid Vehicles Tested over a Four bag FTP at 75 F

5-Cycle City Fuel Economy Formula

The final 5-cycle city fuel economy would be calculated as follows:

$$City\ FE = 0.905 \times \frac{1}{Start\ FC + Running\ FC}$$, where

$$Start\ FC = 0.33 \times \left(\frac{(0.76 \times Start\ Fuel_{75} + 0.24 \times Start\ Fuel_{20})}{4.1} \right)$$, where

$$Start\ Fuel_{75} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{75}} - \frac{1}{Bag\,3\,FE_{75}} \right] + 3.9 \times \left[\frac{1}{Bag\,2\,FE_{75}} - \frac{1}{Bag\,4\,FE_{75}} \right],$$

and

$$Start\ Fuel_{20} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{20}} - \frac{1}{Bag\,3\,FE_{20}} \right]$$, where

$$Running\ FC =$$

$$0.82 \times \left[\frac{0.48}{Bag4_{75}\,FE} + \frac{0.41}{Bag3_{75}\,FE} + \frac{0.11}{US06\,City\,FE} \right] + 0.18 \times \left[\frac{0.5}{Bag2_{20}\,FE} + \frac{0.5}{Bag3_{20}\,FE} \right]$$

$$+ 0.133 \times 1.083 \times [A/C\ FC]$$

where

$$A/C\ FC = \left[\frac{1}{SC03\,FE} - \left(\frac{0.61}{Bag3_{75}\,FE} + \frac{0.39}{Bag4_{75}\,FE} \right) \right]$$, where

US06 City FE = fuel economy in miles per gallon over the city portion of the US06 test,
US06 Highway FE = fuel economy in miles per gallon over the Highway portion of the US06 test,
HFET FE = fuel economy in miles per gallon over the HFET test,
SC03 FE = fuel economy in miles per gallon over the SC03 test.

5-Cycle Highway Fuel Economy Formula

The final 5-cycle highway fuel economy would be calculated as follows:

$$Highway\ FE = 0.905 \times \frac{1}{Start\ FC + Running\ FC}$$, where

$$StartFC\ (gallons\ per\ mile) = 0.33 \times \left(\frac{(0.76 \times StartFuel_{75}) + (0.24 \times StartFuel_{20})}{60} \right)$$,

where

$$Start\ Fuel_{75} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{75}} - \frac{1}{Bag\,3\,FE_{75}} \right] + 3.9 \times \left[\frac{1}{Bag\,2\,FE_{75}} - \frac{1}{Bag\,4\,FE_{75}} \right]$$,

and

$$Start\ Fuel_{20} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{20}} - \frac{1}{Bag\,3\,FE_{20}} \right]$$, and

$$Running\ FC = 1.007 \times \left[\frac{0.79}{US06\ Highway\ FE} + \frac{0.21}{HFET\ FE} \right] + 0.133 \times 0.377 \times [A/C\ FC]$$

where the various symbols have the same definitions as just described above.

Hybrid Vehicles Tested over a Two-Bag FTP at 75°F

5-Cycle City Fuel Economy Formula for Vehicles Tested Over a 2-Bag FTP at 75°F

The final 5-cycle city fuel economy for vehicles tested over a 2-Bag FTP at 75°F would be calculated as follows:

$$City\ FE = 0.905 \times \frac{1}{Start\ FC + Running\ FC}$$, where

$$\text{Start FC} = 0.33 \times \frac{(0.76 \times \text{Start Fuel}_{75} + 0.24 \times \text{Start Fuel}_{20})}{4.1}$$, where

$$Start\ Fuel_{75} = 7.5 \times \left[\frac{1}{Bag\,1/2\,FE_{75}} - \frac{1}{Bag\,3/4\,FE_{75}} \right]$$, where

$$Start\ Fuel_{20} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{20}} - \frac{1}{Bag\,3\,FE_{20}} \right]$$, where

Bag y FE_x = the fuel economy in miles per gallon of fuel during Bag 1 or Bag 3 of the FTP test conducted at an ambient temperature of 75 or 20°F.
Bag x/y FE_x = fuel economy in miles per gallon of fuel during Bags 1 and 2 or Bags 3 and 4 of the FTP test conducted at an ambient temperature of 75°F.

$$Running\ FC =$$

$$0.82 \times \left[\frac{0.90}{Bag3/4_{75}\,FE} + \frac{0.10}{US06\,City\ FE} \right] + 0.18 \times \left[\frac{0.5}{Bag2_{20}\,FE} + \frac{0.5}{Bag3_{20}\,FE} \right]$$

$$+\,0.133 \times 1.083 \times [A/C\ FC]$$

where

$$A/C\ FC = \left[\frac{1}{SC03\,FE} - \left(\frac{1.0}{Bag3/4_{75}\,FE} \right) \right]$$, where

US06 City FE = fuel economy in miles per gallon over the city portion of the US06 test,
US06 Highway FE = fuel economy in miles per gallon over the Highway portion of the US06 test,
HFET FE = fuel economy in miles per gallon over the HFET test,
SC03 FE = fuel economy in miles per gallon over the SC03 test.

5-Cycle Highway Fuel Economy Formula for Vehicles Tested Over a 2-Bag FTP at 75°F

The final 5-cycle highway fuel economy for vehicles tested over a 2-Bag FTP at 75°F would be calculated as follows:

$$Highway\ FE = 0.905 \times \frac{1}{Start\ FC + Running\ FC}$$, where

$$Start\ FC = 0.33 \times \frac{\left(0.76 \times Start\ Fuel_{75} + 0.24 \times Start\ Fuel_{20}\right)}{60} \text{, where}$$

$$Start\ Fuel_{75} = 7.5 \times \left[\frac{1}{Bag\,1/2\,FE_{75}} - \frac{1}{Bag\,3/4\,FE_{75}} \right] \text{, and}$$

$$Start\ Fuel_{20} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{20}} - \frac{1}{Bag\,3\,FE_{20}} \right] \text{, and}$$

$$Running\ FC = 1.007 \times \left[\frac{0.79}{US06\ Highway\ FE} + \frac{0.21}{HFET\ FE} \right] + 0.133 \times 0.377 \times \left[A/C\ FC \right]$$

where the various symbols have the same definitions as just described above.

b. Alternative 5-cycle Highway Fuel Economy Formula

Beginning with the 2011 model year, manufacturers would be allowed to continue to use the mpg-based formulae if the available 5-cycle fuel economy estimates indicated close alignment with the mpg-based formulae. Fuel economy values over all five cycles will be available for one or more vehicle configurations within each durability data group or basic engine group. If the 5-cycle fuel economy values for a specific emission data vehicle are no more than 4% below the mpg-based estimate for city fuel economy and no more than 5% below the mpg-based estimate for highway fuel economy, all the vehicle configurations represented by that emission data vehicle would be allowed to use the mpg-based formulae in complying with the fuel economy label requirements. If the 5-cycle fuel economy values for a specific emission data vehicle are more than 4% below the mpg-based estimate for city fuel economy and more than 5% below the mpg-based estimate for highway fuel economy, all the vehicle configurations represented by that emission data vehicle would be required to use the 5-cycle formulae in complying with the fuel economy label requirements.

It is possible for the 5-cycle fuel economy values to meet the above criteria for either city or highway fuel economy, but not the other. If the 5-cycle fuel economy values for a specific emission data vehicle are more than 4% below the mpg-based estimate for city fuel economy, but no more than 5% below the mpg-based estimate for highway fuel economy, all the vehicle configurations represented by that emission data vehicle would be required to use the 5-cycle formulae in complying with the fuel economy label requirements for both city and highway fuel economy. All five cycles play a significant role in the 5-cycle city fuel economy formula. Once the five tests have been performed for the city estimate, there is little reason not to use the same information to derive the highway fuel economy estimate.

We proposed a different approach for the opposite situation. If the 5-cycle fuel economy values for a specific emission data vehicle are no more than 4% below the mpg-based estimate for city fuel economy, but more than 5% below the mpg-based estimate for highway fuel economy, all the vehicle configurations represented by that emission data vehicle would be allowed to use the mpg-based formulae in deriving the city fuel economy label value. The highway fuel economy value, however, would be based on an alternative, simplified 5-cycle formula as opposed to the full 5-cycle highway fuel economy formula. This alternative 5-cycle highway formula would be based on fuel economy values over the FTP, HFET and US06 tests. The impact of the SC03 test is relatively small due to the speed adjustment factor of 0.377 and air conditioning usage factor of 0.133 in the 5-cycle highway fuel economy formula. The impact of the cold FTP test is small due to the 60 mile trip length assumed for highway driving and the fact that we do not use the actual cold FTP test results to adjust running fuel consumption for colder temperatures during highway driving.

This approach requires that we develop a simplified 5-cycle highway fuel economy formula which is consistent with the full 5-cycle formula. We developed this simplified formula using estimates of the average impact of the SC03 and cold FTP test results on 5-cycle highway fuel economy. In both cases, we estimated this average impact by regressing the impact of these test cycles on the 5-cycle highway fuel economy for the 615 vehicles in our certification database against fuel economy values which would be available from FTP, HFET and US06 testing.

Regarding the impact of the cold FTP on highway fuel economy, we regressed start fuel use in highway driving under a mix of ambient temperature against start fuel use in highway driving at 75°F. As described above, start fuel use in highway driving under a mix of ambient temperature is as follows:

$$Start\ FC = 0.33 \times \frac{\left(0.76 \times Start\ Fuel_{75} + 0.24 \times Start\ Fuel_{20}\right)}{60}$$, where

$$Start\ Fuel_{x} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{x}} - \frac{1}{Bag\,3\,FE_{x}} \right]$$ and x can be either 20°F or 75°F.

The result of the regression was:

Start FC at ambient = 0.005515 + 1.13637 * Start FC at 75°F.

The adjusted r-squared of the regression was very good, over 0.92.

Regarding the impact of SC03 on highway fuel economy, we regressed fuel use due to air conditioning use in highway driving against several estimates of running fuel use, namely Bags 2 and 3 of the FTP, HFET and US06. As described above, fuel use due to air conditioning use is as follows:

$$A/C\ FC = \frac{1}{SC03\,FE} - \left(\frac{0.61}{Bag\,3\,FE_{75}} + \frac{0.39}{Bag\,2\,FE_{75}} \right)$$

In the analysis performed for the NPRM, fuel use over US06 showed the highest level of correlation with air conditioning use. The same was true with the expanded certification fuel economy database. The result of the regression is:

$$A/C\ Fuel\,Use = 0.540 + \frac{0.1357}{US06\,Fuel\ Economy}$$

The adjusted r-squared of this regression is much lower than that for cold start fuel use (0.15). However, the p-values of both coefficients were less than 0.0000001, and thus, are quite statistically significant.

These two relationships can be inserted directly into the 5-cycle fuel economy formula. The result is:

$$Alternative\ Highway\ FE = 0.905 \times \frac{1}{Start\ FC + Running\ FC}$$, where

$$Start\ FC = 0.33 \times \frac{(0.005515 + 1.13637 \times Start\ Fuel_{75})}{60.0}$$, where

$$Start\ Fuel_{75} = 3.6 \times \left(\frac{1}{Bag\,1\,FE_{75}} - \frac{1}{Bag\,3\,FE_{75}} \right)$$, and

$$Running\ FC =$$

$$\left[[1.0 + (0.04 \times 0.18)] \times \left(\frac{0.79}{US06\,Highway\ FE} + \frac{0.21}{HFET\ FE} \right) \right] + \left[0.377 \times 0.133 \times \left(0.00540 + \frac{0.1357}{US06\,FE} \right) \right]$$

Hybrid gasoline-electric vehicles using this modified 5-cycle highway calculation use one of the following equations for start fuel, depending upon whether the vehicle is tested on a 4-bag FTP or a 2-bag FTP.

For a 4-bag FTP:

$$Start\ Fuel_{75} = 3.6 \times \left[\frac{1}{Bag\,1\,FE_{75}} - \frac{1}{Bag\,3\,FE_{75}} \right] + 3.9 \times \left[\frac{1}{Bag\,2\,FE_{75}} - \frac{1}{Bag\,4\,FE_{75}} \right]$$

For a 2-bag FTP:

$$Start\ Fuel_{75} = 7.5 \times \left[\frac{1}{Bag\,1/2\,FE_{75}} - \frac{1}{Bag\,3/4\,FE_{75}} \right]$$

where the various symbols have the same definitions as just described above.

B. Derivation of the MPG-Based Approach

The 5-cycle fuel economy formulae derived above assume that fuel economy estimates are available for specific vehicles for all five dynamometer cycles and their respective bags of emission measurements. As discussed in the preamble to the final rule, these estimates may be based on fuel economy measurements, or on estimates based on test results from a similar vehicle. A simplified approach to implementing the 5-cycle formulae is to apply these formulae to test results on recent model vehicles and develop correlations between the 5-cycle city and highway fuel economy estimates for these vehicles and their fuel economy over the FTP and HFET, respectively. This simplified approach is referred to as the mpg-based approach, since the resultant label adjustment will vary depending on the measured fuel economy (i.e., mpg) of a vehicle over the FTP and HFET tests.

The database from which the mpg-based correlations were derived consisted of 615 2003-2006 model year vehicles, including 14 hybrids and one diesel vehicle. All vehicles had been tested over all five certification test cycles. In most cases, bag-specific fuel economy measurements were also available, but in some cases they were not. In the latter cases, we estimated FTP bag-specific fuel economy using relationships between bag and whole cycle fuel economy which were developed from those vehicles with bag fuel economy data. The following table shows the relationships between bag and cycle fuel economy from our 5-cycle fuel economy database for the standard and cold FTP.

Table III.B-1. Ratio of FTP Bag to Cycle Fuel Consumption

	No. of Vehicles	Bag 1	Bag 2	Bag 3
Standard FTP				
Mean	389	1.047	1.036	0.897
Standard Deviation		0.040	0.029	0.036
Coefficient of Variation		3.8%	2.8%	4.0%
Cold FTP				
Mean	330	1.171	1.013	0.855
Standard Deviation		0.055	0.028	0.036
Coefficient of Variation		4.7%	2.8%	4.2%

The 5-cycle formulae also require separate fuel economy estimates for the city and highway portions of US06. These measurements have not been taken on a regular basis. In the Draft Technical Support Document to the NPRM, we analyzed US06 city and US06 highway fuel economy data for 85 vehicles which was available. There we found that the fuel economy of the US06 city bag averaged 68% of that over the entire US06 cycle for conventional vehicles, and 77% for two hybrid vehicles. We also found that the fuel economy of the US06 highway bag averaged 116% of that over the entire US06 cycle for conventional vehicles, and 109% for two hybrid vehicles.

For the NPRM, we projected the impact of the 5-cycle approach by applying the relationships for conventional vehicles to all vehicles, including hybrids. For the FRM, we believe that it would be more accurate to apply the relationships for the two hybrids that were tested to all the hybrid vehicles in the certification database. While only two hybrids were tested over a two-bag US06 test, the fact that fuel economy over the US06 city bag was closer to that over the entire US06 cycle than with conventional vehicles is very consistent with the effect of hybrid technology on fuel economy. That is, hybrid technology is generally more effective during lower speed, stop and go driving than at consistently high vehicle speeds. Which relationship is used to project US06 city and highway fuel economy values has no effect in the future for vehicles whose label values are set using the 5-cycle formulae. In this case, US06 city and highway fuel economy values will be measured, not estimated. However, the projections made here can affect the mpg-based equations, as these equations are based on projected 5-cycle fuel economy values. These projections for hybrids with the highest fuel economy values are particularly important, as these vehicles can affect the shape of the mpg-based equations at high fuel economy values. Fortunately, the two hybrids for which we have US06 city and highway fuel economy testing are hybrids with very high fuel economy values (a Prius and a Civic hybrid). Thus, using the relationships between US06 city, US06 highway and US06 fuel economy values based on the testing of these two vehicles to all hybrids in the certification database should be most accurate in the range of fuel economy where the mpg-based equations are most affected by hybrids.

One additional adjustment was made to Cold FTP fuel economy values of all vehicles. This adjustment is related to the new requirement that the heater or defroster be turned on during the Cold FTP test. In order to estimate the impact of this change on fuel economy, EPA tested two conventional vehicles and two hybrid vehicles at 20°F with the heater turned on and off.[37] The results are shown in Table III.B-2.

Table III.B-2. Effect of Heater/Defroster Use on Cold FTP Fuel Use

	Bag 1	Bag 2	Bag 3	FTP
Fuel Economy: Heater off (mpg)				
Odyssey	13.5	16.3	18.5	16.2
Trailblazer	11.4	13.8	15.6	13.6
Prius	32.4	50.4	39.0	44.1
Civic Hybrid	30.2	38.2	40.8	38.2
Fuel Economy: Heater on (mpg)				
Odyssey	13.0	15.2	17.4	15.3
Trailblazer	11.2	13.2	15.2	13.2
Prius	28.5	34.1	37.9	36.2
Civic Hybrid	26	29.1	34.6	31.7
Fuel Consumption: Heater off (gallon per 100 miles)				
Odyssey	7.42	6.12	5.42	6.16
Trailblazer	8.79	7.25	6.40	7.33
Prius	3.086	1.984	2.564	2.268
Civic Hybrid	3.311	2.618	2.451	2.618
Fuel Consumption: Heater on (gallon per 100 miles)				
Odyssey	7.67	6.58	5.76	6.55
Trailblazer	8.89	7.56	6.59	7.57
Prius	3.509	2.933	2.639	2.762
Civic Hybrid	3.846	3.436	2.890	3.155
Increase in Fuel Consumption (%)				
Odyssey	3.5%	7.5%	6.3%	6.4%
Trailblazer	1.2%	4.4%	2.9%	3.2%
Average	2.3%	6.0%	4.6%	4.8%
Prius	13.7%	47.8%	2.9%	21.8%
Civic Hybrid	16.2%	31.3%	17.9%	20.5%
Average	14.9%	39.5%	10.4%	
Increase in Fuel Consumption after adjusting for test procedure differences (%)				
Odyssey	2.3%	3.8%	3.2%	N/A
Trailblazer	1.2%	2.2%	1.4%	N/A
Average	1.7%	3.0%	2.3%	N/A
Prius	13.7%	47.8%	2.9%	21.8%
Civic Hybrid	16.2%	31.3%	17.9%	20.5%
Average	14.9%	39.5%	10.4%	

The test procedure used in this testing differs from that being promulgated in the final rule. In this testing, the defroster was turned on to the maximum position immediately at the start of the test and held there throughout the test. This is a more severe setting than we are promulgating, where the start of defrosting is being delayed two minutes and then reduced to a more moderate setting during Bags 2 and 3. To account for these differences, we reduced the impact of defrosting on fuel consumption for conventional vehicles. These reduced impacts are shown in the final section in Table III.B-2. Specifically, we reduced the adjusted the impacts during Bags 2 and 3 by a factor of two. We also reduced the impact on Bag 1 fuel consumption for the Odyssey to reflect the relative impact for the Odyssey on Bags 2 and 3 compared to those for the Trailblazer. The Bag 1 impact for the Trailblazer was not adjusted, because it was tested with the delay in defroster start-up being promulgated. Thus, the fuel consumption of conventional vehicles over Bags 1, 2, and 3 of the Cold FTP test in our 5-cycle certification database were increased by 1.7%, 2.9%, and 2.2%, respectively, to account for defroster use in future testing.

As can be seen from Table III.B-2, the effect of defroster and heater use was much larger for the two hybrids than for the two conventional vehicles. (The temperature control was also turned to hot when the defroster was turned on during the hybrid testing.) This greater impact is likely due to the fact that operating the heater prevents the engine from shutting off during certain driving modes, like idling and decelerations. The same effect likely occurs when the heater is turned on without the defroster. Since drivers regularly use their heater under colder ambient conditions, this effect is occurring currently in-use. While the final Cold FTP test procedure is more moderate than that used in the above testing of hybrids, we believe that the great majority of the impact on hybrid fuel consumption was due to the elimination of the engine shut-off feature, as opposed to the specific defroster/heater setting. Thus, we did not believe that the retesting of these vehicles with the final test procedure would produce significantly lower fuel consumption impacts. We expect that auto manufacturers will modify their hybrid designs in the future to reduce this impact. However, as the mpg-based equations will be applied to vehicles as early as the 2008 model year, we believe that they should reflect current technology as much as possible. Also, hybrids which reflect improved technology in this regard can utilize the 5-cycle formulae, especially since hybrid models are always tested over all five dynamometer cycles during certification due to their unique features. Thus, we are applying the average impacts on Bag 1, 2, and 3 fuel consumption, as measured in the above test program, to hybrid fuel consumption in our 5-cycle certification database.

Using the fuel economy values which are now available for all bags and cycles for all 65 vehicles, we calculated 5-cycle city and highway label values. We then developed relationships between the 5-cycle city and highway label values and FTP and HFET fuel economy values, respectively, using the least squares regression function in Excel. As we did for the NPRM, we performed these regressions in terms of fuel consumption (i.e., gallons per mile or the inverse of fuel economy). For 5-cycle city fuel economy, the best fit relationship was:

$$\text{5-cycle city FE} = 1 / (0.003259 + 1.18053 / \text{FTP FE})$$

The adjusted r-squared for this regression was 0.990. For 5-cycle highway fuel economy, the best fit relationship was:

$$\text{5-cycle highway FE} = 1 / (0.001376 + 1.3466 / \text{HFET FE})$$

The adjusted r-squared for this regression was again slightly worse, 0.952. Figures III-8 and 9 show the relationship between the inverse of 5-cycle city and highway fuel economy (i.e., fuel consumption) versus the inverse of FTP or HFET fuel economy. The first graph shows city fuel consumption, while the second shows highway fuel consumption.

Figure III-8. 5-Cycle City Versus FTP Fuel Consumption

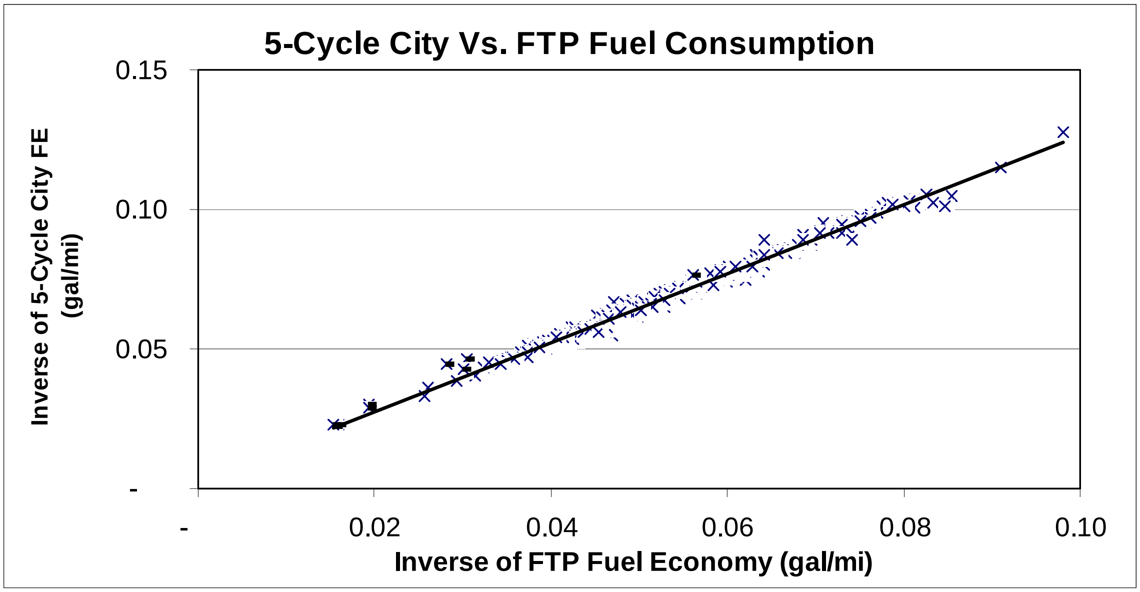
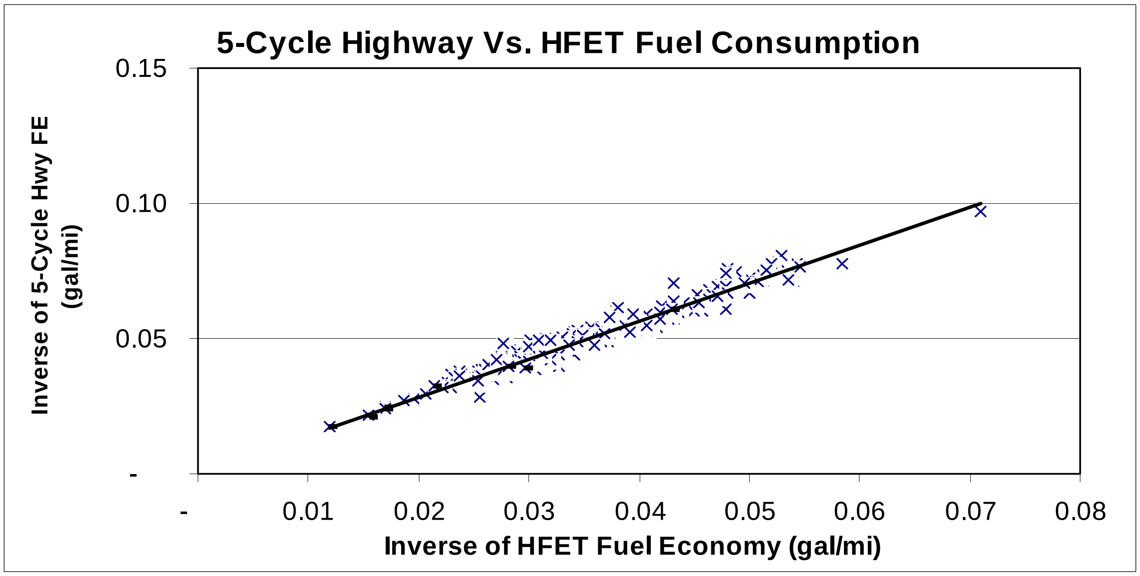


Figure III-9. 5-Cycle Highway Versus HFET Fuel Consumption



Figures III-10 and 11 show the relationship between 5-cycle city and highway fuel economy (i.e., fuel consumption) versus of FTP or HFET fuel economy. The first graph shows city fuel consumption, while the second shows highway fuel consumption. As can be seen by comparing the two sets of graphs, the relationships are linear in terms of fuel consumption, but become curved in terms of fuel economy.

Figure III-10. MPG-Based City Fuel Economy

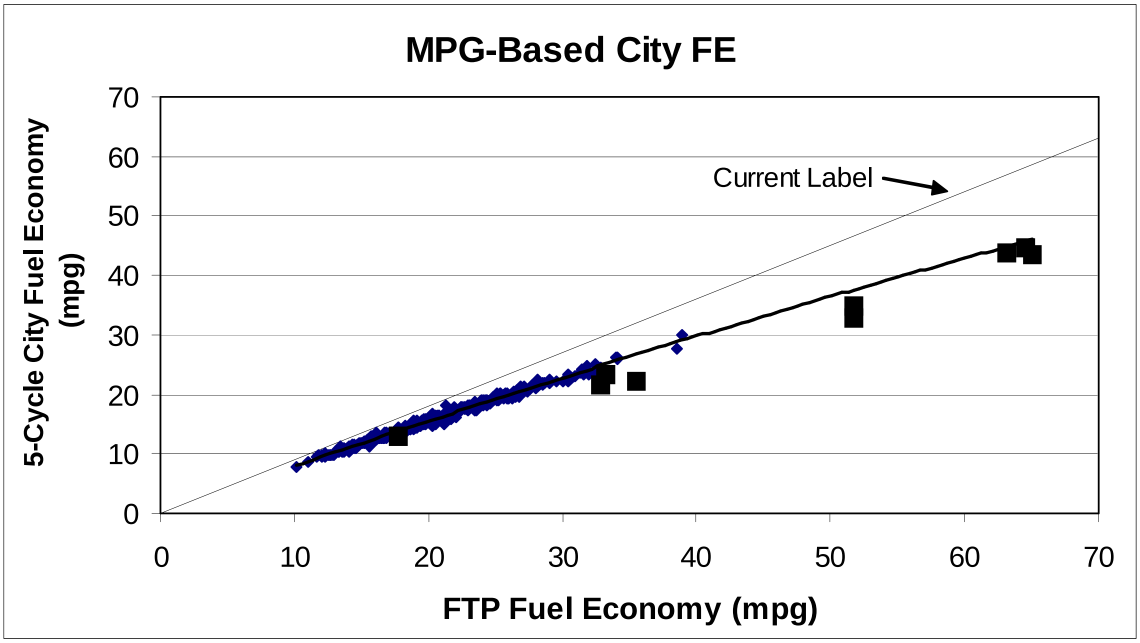
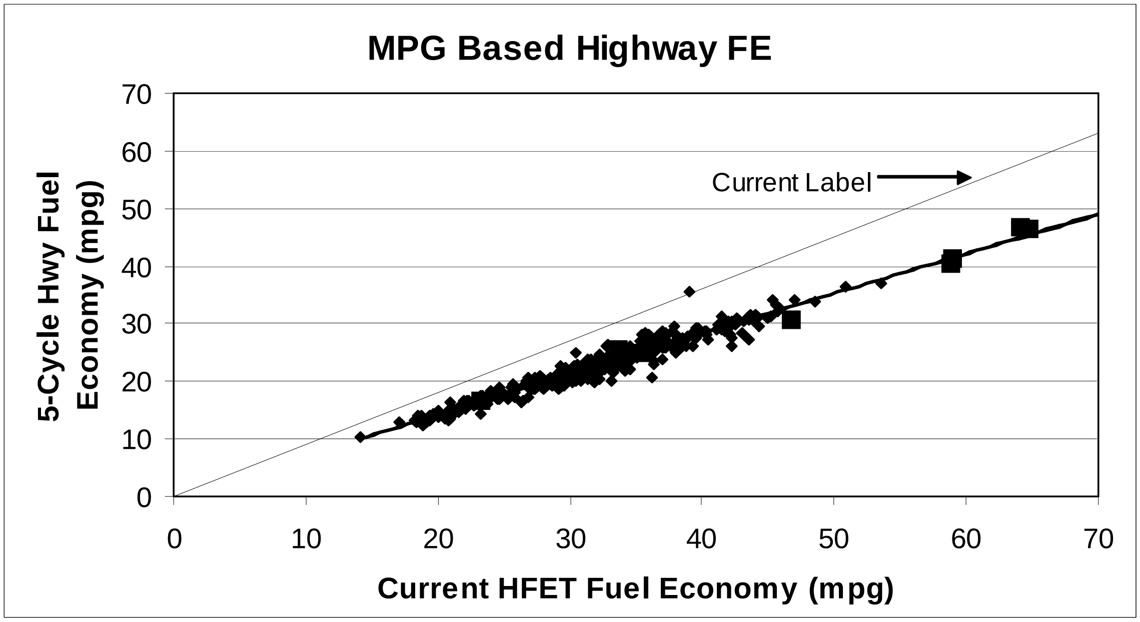


Figure III-11. MPG-Based Highway Fuel Economy



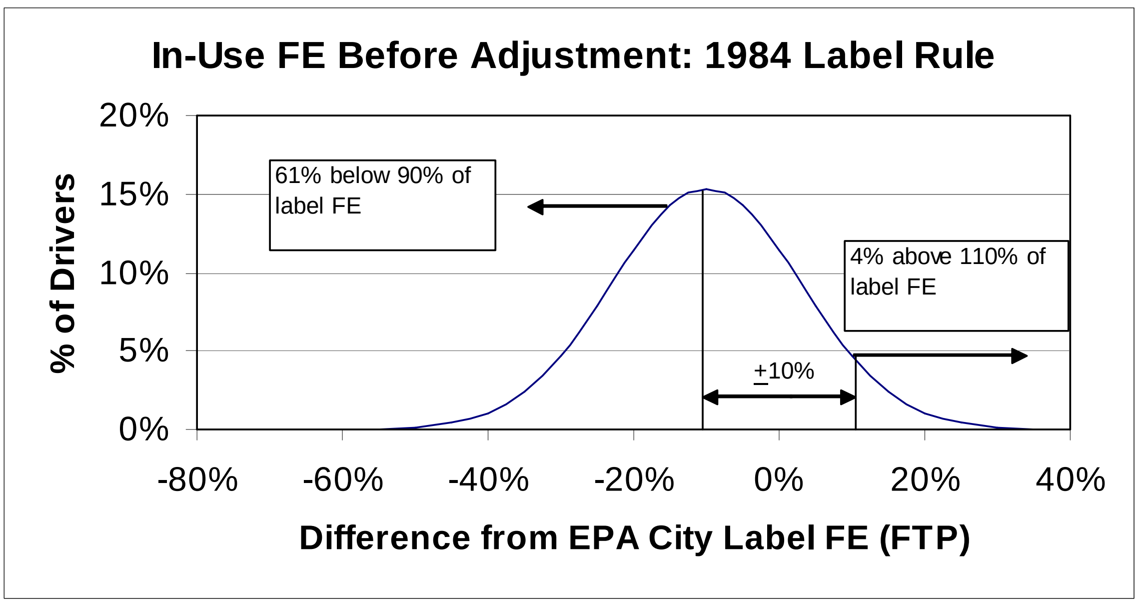
The standard error of the difference between the mpg-based equations and the 5-cycle fuel economies are 0.5 mpg and 1.15 mpg for city and highway fuel economy, respectively. These differences represent 3% of the average 5-cycle city fuel economy and 5% of the average 5-cycle highway fuel economy, respectively. Thus, while the mpg-based equations are able to reflect much of the difference in fuel economy represented by the 5-cycle formulae, differences between the fuel economy of individual vehicles on the order of 0.5-1.1 mpg are muted by the mpg-based approach.

C. Variability in Onroad Fuel Economy

As described in the preamble to the final rule, EPA is proposing to continue to set the city and highway mpg estimates at a level that reflects average fuel economy. However, we desire the fuel economy label to indicate the range of onroad fuel economy that drivers might experience. Therefore, it is important to understand the variability of onroad fuel economy.

We begin with a review of the work done in this area for the 1984 fuel economy adjustment rule. At that time (circa 1982), EPA conducted a systematic review of the onroad fuel economy experienced by over 40,000 drivers compared to the EPA fuel economy labels for each vehicle.[38] Vehicles were separated into 3 categories: 1) primarily city driven, 2) primarily highway driven, and 3) mix of driving. The percentage differences between onroad and either the EPA city or highway fuel economy label was determined for the first two groups. The results were generally normally distributed. The results for city driven vehicles are depicted in Figure III-12.

Figure III-12. Onroad FE Versus Pre-1984 EPA City Label for City Driven Cars



The analysis of the onroad fuel economy by primarily city drivers found that average onroad fuel economy was 90% of the then current EPA city label (i.e., a 10% shortfall on average). At that time, the city label value was simply the fuel economy over the FTP. As shown in Figure III-12, only 4% of all drivers achieved an onroad fuel economy more than 10% of their vehicle's city fuel economy label. And 61% achieved an onroad fuel economy less than 90% of their vehicle's city label.

Assuming a normal distribution of the onroad fuel economy of any specific vehicle, as was done in the 1984 label adjustment rule, it is possible to use this information to calculate a coefficient of variation for the difference between onroad fuel economy and EPA's city label. As shown in Figure III-12, 4% of all predominantly city drivers achieved more than 110% of the EPA city fuel economy label. For a normal distribution, 4% of the population exceeds the mean of the population plus 1.75 times the standard deviation. In this case, since the population is in percentage terms (onroad fuel economy divided by label fuel minus 1.0), the standard deviation is equal to the coefficient of variation in the ratio of onroad fuel economy to EPA label value. Likewise, 61% of all predominantly city drivers achieved less than 90% of the EPA city fuel economy label. Another way to put this is that 39% of all drivers achieved more than 90% of the EPA city fuel economy label. For a normal distribution, 39% of the population exceeds the mean of the population plus 0.279 times the coefficient of variation. Thus, 20% of the EPA city fuel economy label (110% minus 90%) represents 1.471 (1.75 minus 0.279) times the coefficient of variation. The coefficient of variation for this distribution is therefore 13.6% (20% divided by 1.471).

The comparison of onroad fuel economy and EPA highway label for highway driven vehicles yielded similar results. In the case of onroad fuel economy during highway driving, only 8% of all predominantly highway drivers achieved an onroad fuel economy more than 110% of their vehicle's highway fuel economy label. Of all predominantly highway drivers, 34% achieved an onroad fuel economy within 10% of their vehicle's highway label and 58% achieved an onroad fuel economy below 90% of their vehicle's highway label. These percentages apply prior to the 22% downward adjustment to the highway fuel economy label implemented in that rulemaking.

Again for a normal distribution, 8% of the population exceeds the mean of the population plus 1.405 times the coefficient of variation. Likewise, 42% (8% plus 38%) of all drivers achieved more than 90% of the EPA highway fuel economy label. For a normal distribution, 42% of the population exceeds the mean of the population plus 0.202 times the coefficient of variation. Thus, 20% of the EPA highway fuel economy label (110% minus 90%) represents 1.203 (1.405 minus 0.202) times the coefficient of variation. The coefficient of variation for this distribution is therefore 16.6% (20% divided by 1.203).

The goal of the final 10% and 22% adjustments was to move the average onroad fuel economy closer to either the city or highway label value, as applicable. These adjustments, however, do not affect the underlying variability of the data. They increase the coefficients of variation slightly, because they reduce the denominator (the EPA label value) by 10% or 22%, respectively. They primarily shift the distribution over by 10% or 22%. However, EPA did analyze the effect of more complex adjustments, which depended on the several vehicle factors, such as front versus rear wheel drive, manual or automatic transmission, gasoline or diesel engine, etc. Applying this more complex system of adjustments reduced the variability in onroad versus EPA label fuel economy somewhat. For city driven vehicles, the coefficient of variation decreased to 13.1%, while that for highway driven vehicles decreased to 14.1%. Since the 5-cycle formulae basically adjust fuel economy in a similar fashion (i.e., some vehicles receive more of an adjustment than others), we believe that it these somewhat smaller coefficients of variation are more indicative of what drivers would experience with vehicles labeled using the 5-

cycle formulae. Thus, we will use a coefficient of variation of 13-14% to determine an adjustment that would convert a mean fuel economy into a 25th percentile fuel economy. As discussed above, 75% of the population of a normal distribution exceeds the mean minus 0.675 times the standard deviation (or coefficient of variation in this case). Applying this factor to our estimate of the coefficient of variation of 13-14% yields an offset of 9-10%.

Oak Ridge National Laboratory (ORNL), sponsored by the Department of Energy, has recently begun a program where drivers can submit their own fuel economy measurements via the Internet.[39] The program is commonly referred to as "Your MPG." The Your MPG data are similar in nature to the much larger databases analyzed for the 1984 label adjustment rule. Drivers measure their own fuel economy and provide a perceived split of their driving into city and highway categories. The strength of this type of data is the fact that the vehicle is being operated by the owner or regular driver in typical use. The weaknesses are the unknown representativeness of the sample, the unknown nature of the technique used by the owner/driver to measure fuel economy and the short time period over which fuel economy is generally assessed (e.g., as short as a tank full of fuel or two). In the particular case of the ORNL database, its current size is still small (8180 estimates of fuel economy for 4092 vehicles) compared to those available in 1984, though it is growing daily.

We compared the fuel economy estimates submitted to the ORNL website with each vehicle's fuel economy label. We combined the city and highway labels using each driver's estimate of the percentage of their driving that was city-like and highway-like. If a driver did not provide an estimate of the breakdown of their driving pattern, we assumed that their driving was 55% city and 45% highway. We calculated the percentage difference between the onroad fuel economy and the current composite EPA label value. (A more detailed discussion of these estimates is presented in Chapter II of this Final Technical Support Document .) The average difference for more than 7300 individual fuel economy estimates was -1.4%, meaning that onroad fuel economy was just slightly lower than the composite EPA label value using the split of city and highway driving estimated by the driver. This metric is analogous to those presented above from the early 1980's, as vehicles were segregated then into those with predominantly city or highway driving. The standard deviation in this percentage difference was 13%, very consistent with the estimates derived above.

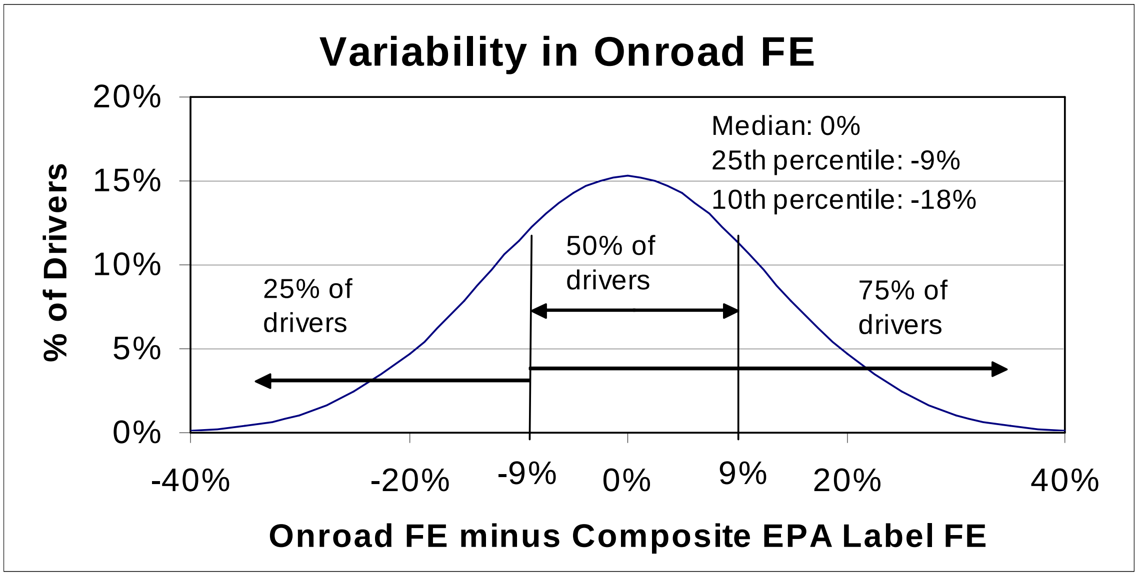
Another source of onroad fuel economy data is the recent testing of over 100 vehicles in the Kansas City area. Valid onroad fuel economy measurements were obtained for roughly one day of driving from roughly 100 vehicles. The average onroad fuel economy was 30.4 mpg, while the average composite EPA label value was 31.4 mpg. The standard deviation of the percentage difference between onroad fuel economy and EPA composite fuel economy was 14%. This is only slightly higher than the estimates from the early 1980's and the Your MPG website. We would have expected a larger variability than these other sources for two reasons. One, we did not segregate vehicles into primarily city and highway driving categories or account for the predominance of one or the other type of driving. Two, driving can vary significantly from day to day. With only one day's worth of driving measured, the variability in fuel economy would be expected to be much higher than if a week or two of driving were assessed. At the same time, all of these vehicles were located within a single metropolitan area, so their driving did not reflect much urban/rural diversity, nor the diversity likely present between urban areas.

And only 100 vehicles were assessed, including a unrepresentatively high number of hybrids. (The standard deviation only increased to 15% when the hybrids were excluded.) Thus, the small sample may be a factor.

Finally, we evaluated the variability in the Consumer Report fuel economy measurements compared to the current EPA city and highway label values. (See section II.B.1 for a more complete discussion of the Consumer Report fuel economy estimates.) The standard deviations of the percentage difference between the Consumer Report and current EPA fuel economy were 8% for city and 7% for highway. These figures are lower than the 13-16% value found during the 1985 label adjustment rule and in the ORNL Your MPG database. However, Consumer Report adjusts their fuel economy measurements to represent a single ambient temperature and all of their testing follows the same road routes. Thus, both the ambient conditions and the driving patterns are much more consistent than those experienced by the population of drivers in the U.S. The fact that variability is still as high as 7-8% tends to confirm that the 13% assumption described above is reasonable.

All of the above estimates of the standard deviation in the percentage difference between onroad and EPA label fuel economy fall in the range of 13-16%. The more recent estimates fall towards the lower end of this range. Thus, we will select 13% as the best point estimate of variability. Multiplying the standard deviation by 67.5% produces an offset from mean fuel economy which should encompass an additional 25% of drivers. The 5-cycle formulae derived in section III.A and the mpg-based formulae derived in section III.B, including the 11% downward adjustment for non-dynamometer effects, represent estimates of mean onroad fuel economy. All of the inputs to the 5-cycle formulae are based on national averages of the relevant parameter. Thus, reducing these estimates by 9% (i.e., multiplying them by 0.91) would convert these figures from the mean fuel economy achieved on the road to the 25th percentile of the range of onroad fuel economies achieved. This would produce a label value which would be achieved or exceeded by 75% of all drivers. Figure III-20 depicts this graphically.

Figure III-13. Variability in Onroad FE



The frequency distribution of onroad fuel economy shown in Figure III-13 assumes that the 5-cycle formulae developed above match onroad fuel economy on average In this case, 25% of drivers achieve an onroad fuel economy below 90% of their label value and 25% achieve an onroad fuel economy above 110% of their label value. Half of all drivers achieve an onroad fuel economy within plus or minus 9% of their label value.

The adjustment appropriate to convert mean fuel economy estimates to those representative of other percentiles is straightforward. For example, the 10th and 90th percentile fuel economy values would be 1.28 times the coefficient of variation off of the mean value, or 17% downward and upward adjustments from the mean. The 5th and 95th percentile fuel economy values would be 1.645 times the coefficient of variation off of the mean value, or 21% downward and upward adjustments from the mean.

D. Impact of the 5-Cycle and MPG-Based Formulae on Fuel Economy Labels

The impact of the final rule on city and highway fuel economy label values was assessed using the same database of 615 late model year vehicles used to develop the mpg-based adjustments above. It should be noted that these data are not sales weighted. In fact, most specific vehicle models included in the database are “worst case” for emission performance purposes within their model group, as this is currently one of the criteria used by EPA to determine which vehicles should be tested over the US06, SC03 and cold FTP tests for emissions compliance. Table III.D-1 presents the results of this comparison for all 615 vehicles, as well as various sub-sets of vehicles.

Table III.D-1. Current and 5-Cycle Label Fuel Economies by Model Type[i]

	Current City	5-Cycle City	Current Highway	5-Cycle Highway
Conventional Vehicles				
Large car	15.7	13.8	21.9	19.7
Midsize car	20.5	17.8	27.9	25.6
Minivan	17.4	15.2	23.6	20.9
Pickup	15.1	13.2	18.9	17.2
Small car	20.7	18.1	27.3	25.3
Station wagon	20.3	17.6	26.6	23.5
SUV	16.8	14.6	21.6	19.5
Van	12.5	10.9	16.0	14.3
All conventional	**18.6**	**16.2**	**24.6**	**22.4**
All hybrids	41.6	32.0	40.6	36.8
Diesel (one midsize car)	26.2	22.7	35.3	31.4
All vehicles	19.1	16.4	24.9	22.7

The next table shows the effect of the 5-cycle formulae on conventional gasoline fueled vehicles with particularly high or low fuel economy.

Table III.D-2. Current and 5-cycle Label Fuel Economy by Propulsion System

	City			Highway		
	Current (mpg)	5-Cycle (mpg)	Percent Change	Current (mpg)	5-Cycle (mpg)	Percent Change
Hybrids	42.7	33.0	-22.3%	42.8	36.9	-12.9%
Diesel	26.2	23.4	-10.7%	35.3	32.0	-9.3%
Conventional Gasoline-Fueled Vehicles						
12 Highest FE	30.9	26.9	-12.9%	36.6	34.0	-6.9%
12 Lowest FE	10.2	9.5	-6.9%	14.8	14.8	-0.2%
Average	18.6	16.5	-10.8%	24.6	22.8	-7.4%

As can be seen from Tables III.D-1 and III.D-2, use of the 5-cycle formulae would reduce both current city and highway fuel economy label values. For conventional vehicles, city and highway fuel economy values would be reduced an average of 13% and 9%, respectively. For higher than average fuel economy vehicles, the reduction in city fuel economy would be slightly higher, while for lower than average fuel economy vehicles, the reduction in city fuel economy would be slightly lower. The change in highway fuel economy is essentially independent of current highway fuel economy.

[i] These figures may differ from those that might appear on the EPA fuel economy window sticker, as they have not undergone any sales weighting. They have been derived by applying fuel economy label formulae (e.g., 0.9 times FTP fuel economy) to fuel economy test results for individual vehicles.

The impact on hybrid vehicles would be significantly greater for city fuel economy, averaging a 23% reduction. However, the reduction in highway fuel economy would be the same as for conventional gasoline-fueled vehicles. This greater impact occurs primarily because a number of the fuel efficient aspects of hybrid vehicles produce their maximum benefit under conditions akin to the FTP tests, and are somewhat less beneficial during aggressive driving, colder ambient temperatures and when the air conditioner is turned on. The impacts of the 5-cycle formulae on the single diesel vehicle in the database are very similar to those for conventional gasoline fueled vehicles.

The impact of the mpg-based formulae would be very similar on average to those shown in Tables III.D-1 and III.D-2 above for conventional vehicles, gasoline-fueled and diesel. This is not surprising for conventional gasoline fueled vehicles, since the mpg-based formulae are based essentially on the average results of the 5-cycle formulae and the vast majority of the vehicles in the database are conventional gasoline-fueled vehicles. The 5-cycle fuel economy values for the one diesel in the database also fall very near the mpg-based curves. However, the impact of the mpg-based formulae on the current city fuel economy label values for hybrids would vary significantly from the 5-cycle values. Basically, the impact on hybrids would reflect that of conventional vehicles with the same current fuel economy levels. The mpg-based regressions therefore, represent essentially the impact of the 5-cycle formulae on conventional vehicles, which is less than that for hybrids. The impact on the mpg-based formulae for hybrids is shown in Table III.D-3 below. The impact on the city fuel economy label is still somewhat higher (-18%) than the average for conventional gasoline vehicles, because the average FTP city fuel economy for hybrids is higher than that for even the top 12 conventional gasoline fueled vehicles (-15%). The impact of the mpg-based formula on the highway label value for hybrids is 10%, or just slightly higher than that for conventional gasoline-fueled (9%). With only one diesel vehicle in the database, no general observations about this engine type can be made.

Table III.D-3. Effect of MPG-Based Formulae on City and Highway Fuel Economy

	City			Highway		
	Current (mpg)	MPG-Based	Percent Change	Current (mpg)	5-Cycle (mpg)	Percent Change
Hybrids	41.6	34.1	-18%	40.6	36.8	-10%
Conventional	18.6	16.2	-13%	24.6	22.4	-9%

In addition to looking at the overall change in fuel economy estimates for all vehicles in the database, we also focused on those manufacturers responsible for the majority of sales in the U.S. This approach may better reflect the changes likely to be seen by the majority of consumers. In effect, Table II-3 above includes vehicles by Aston Martin and Rolls-Royce in the percent change, and these vehicles are weighted equally with cars made by GM, Ford, DaimlerChrysler, and other top-selling manufacturers. According to Autodata Corporation, the seven manufacturers with the greatest U.S. market share account for more than 90 percent of U.S. sales. Table II.D-4 shows these manufacturers, their 2005 U.S. market share, and the average percent change in city and highway fuel economy estimates for each of these manufacturers as represented in our database. It is important to note, however, that these estimates are not intended to represent or include the entirety of a manufacturer's product line, and should not be interpreted as such. These estimates are derived from our database of 615 test vehicles for which data on all five emission and fuel economy test procedures is available, and because of differing ways in which manufacturers test their vehicles and submit data to EPA, the database may not reflect the range of makes and models similarly across manufacturers.

Table II.D-4. Effect of New Methods on Fuel Economy Estimates for Major Manufacturers

Manufacturer	2005 U.S. Market Share (%)*	Average Change in City Fuel Economy Estimate	Average Change in Highway Fuel Economy Estimate
General Motors	25.9	-10%	-11%
Ford Motor Co.	17.9	-12%	-10%
DaimlerChrysler	14.9	-10%	-11%
Toyota	13.7	-11%	-7%
Honda	8.9	-13%	-7%
Nissan	6.1	-11%	-7%
Hyundai	2.9	-13%	-8%
Average		**-12%**	**-8%**

* Source: Autodata Corp., Woodcliff Lake, New Jersey.

The following table shows the effect of the various aspects of the 5-cycle formulae on 5-cycle city and highway fuel economy relative to fuel economy over the FTP and HFET, respectively.

Table III.D-5. Effect of Various Factors on 5-cycle Fuel Economy

<table>
<tr><th rowspan="2"></th><th colspan="2">City FE</th><th colspan="2">Highway FE</th></tr>
<tr><th>Conventional</th><th>Hybrid</th><th>Conventional</th><th>Hybrid</th></tr>
<tr><td>Start Fuel</td><td>1.2%</td><td>1.0%</td><td rowspan="2">0.6%</td><td rowspan="2">0.7%</td></tr>
<tr><td>Cold Temp Start</td><td>1.4%</td><td>4.5%</td></tr>
<tr><td>Cold Temp Running</td><td>2.1%</td><td>10.1%</td><td>0.7%</td><td>0.7%</td></tr>
<tr><td>A/C</td><td>3.2%</td><td>5.5%</td><td>2.8%</td><td>3.7%</td></tr>
<tr><td>Running</td><td>3.8%</td><td>4.0%</td><td>16.8%</td><td>20.9%</td></tr>
</table>

E. Sensitivities and Uncertainties in the 5-Cycle Fuel Economy Formulae

In this section, we evaluate the impact of a series of alternative assumptions and approaches to developing the 5-cycle fuel economy formulae. The organization of this section basically follows that of section II.A above. Alternatives regarding start fuel use are addressed, followed by those affecting running fuel use at 75°F, fuel associated with air conditioning use and the impact of colder temperatures.

1. Start Fuel Use

There are five key factors which affect start fuel use on a gallon per mile basis. These are: 1) the distribution of starts as a function of soak time and time of day, 2) the effect of soak time and ambient temperature on start fuel use, 3) fuel consumption associated with a cold start, 4) average trip length, and 5) heater/defroster use. Each of these factors will be addressed below in turn.

Regarding the distribution of starts as a function of soak time and time of day, we know of no other existing estimate which is as representative and extensive as the Baltimore-Spokane data used to develop the MOBILE6.2 and Draft MOVES2004 distributions. The recent testing in Kansas City covers nearly as many vehicles. However, the number of days of driving assessed for each vehicle is well below that achieved in Baltimore and Spokane. Georgia Tech has been studying driving patterns in Atlanta via vehicle instrumentation for some time. The amount of data which they have collected to date exceeds that obtained in Baltimore and Spokane. EPA has begun to obtain the start and trip related information from this study. However, the work involved is considerable and the results are not yet available.

Regarding the effect of soak time and ambient temperature on start fuel use, the correlations used in Draft MOVES2004 and EMFAC2000 are both recent and addressed essentially all data available at that time. We know of no other data addressing the effect of soak time on start fuel use. Some information regarding the impact of ambient temperature on start fuel use at 50°F is available from California certification testing. California requires a small number of vehicles to have their emissions tested at 50°F each year. We obtained this data for nine conventional Honda vehicles, two Honda hybrids and two Toyota hybrids.

The nine conventional Honda vehicles showed slightly lower sensitivity of start fuel use to temperature than that estimated in Draft MOVES2004. At 50°F and 20°F, the nine vehicles showed 1.51 and 2.30 times the start fuel use as at 75°F, respectively. (Start fuel use being defined as 3.59 miles times the difference in fuel consumption in Bags 1 and 3 of the FTP.) Draft MOVES2004 estimates ratios of 1.63 and 2.75 at 50°F and 20°F, respectively. The 90% confidence intervals around the means of the Honda data were roughly half of the difference between the means for the Honda vehicles and the Draft MOVES2004 estimates (i.e., 0.07 and 0.20, respectively). We do not have estimates for the confidence limits around the Draft MOVES2004 estimates. However, given the greater number of vehicles tested, the confidence intervals around the Draft MOVE2004 projection are probably smaller. Thus, while 1-4 individual Honda vehicles showed a greater sensitivity to temperature than projected by Draft MOVES2004, on average the Honda vehicles are less sensitive at a 90% confidence level.

We re-estimated the weighting for start fuel use at 20°F and 75°F using the temperature sensitivity of the average Honda conventional vehicle. We modified the coefficients of the Draft MOVES2004 equation for the ratio of start fuel use as a function of temperature to match the ratios of 1.51 and 2.30 at 50°F and 20°F, respectively. The resulting equation was:

$$\text{Start fuel at T / Start fuel use at 75°F} = 1 - 0.0170 * (T - 75) + 0.00013 * (T - 75)^2$$

Using this equation, we found that the weighting for start fuel use at 20°F and 75°F changed in the third decimal place, but remained the same when rounded to two decimal places (0.24 and 0.76, respectively). This is likely the result of the fact that the Honda vehicles were less sensitive at both 50°F and 20°F. Thus, the effect of lower temperature sensitivity at 50°F is appropriately reflected in the 5-cycle formulae by the lower start fuel use measured during the cold FTP at 20°F.

All four hybrid vehicles showed greater sensitivity to temperature at 20°F than projected by Draft MOVES2004, but only three showed greater sensitivity at 50°F. Table III.E-1 shows the temperature sensitivities of these four vehicles.

Table III.E-1. Sensitivity of Hybrid Start Fuel Use to Ambient Temperature

Vehicle	Ratio of Start Fuel Use at Temperature X to 75°F		Weight of Start Fuel Use at 20°F
	X = 50°F	X = 20°F	
Honda Insight	1.99	3.68	0.24
Honda Accord	2.02	2.93	0.30
Toyota 2004 Prius	1.45	4.40	0.14
Toyota RX 400H	2.55	4.68	0.26
Draft MOVES2004	1.63	2.74	0.24

As can be seen, the calculated 20°F cold start weights range from 0.14-0.30 for the four hybrids, compared to 0.24 based on Draft MOVES2004. On average, the results for the four hybrids essentially match that based on Draft MOVES2004. Individually, the Prius and the RX 400H data produce cold temperature weights very similar to that based conventional vehicles. The Honda Accord data produces a greater weight for cold start fuel use at 20°F, due to the fact that its cold start fuel use at 50°F is high relative to that at 20°F. The opposite is true for the 2004 Prius. Using a weight of 0.30 for cold start fuel use at 20°F for the Accord hybrid would reduce its 5-cycle city fuel economy by 0.1 mpg from 21.6 to 21.5 mpg. Using a weight of 0.14 for cold start fuel use at 20°F for the 2004 Prius would increase its 5-cycle city fuel economy by 0.5 mpg from 43.6 to 44.1 mpg. In both cases, 5-cycle highway fuel economy would be unaffected.

Based on this limited data, it appears unlikely that uncertainty in the effect of ambient temperature on start fuel use would significantly affect city 5-cycle fuel economy. It is certain to have no effect on 5-cycle highway fuel economy, due to the extremely low contribution of start fuel use in highway driving. Hybrids would likely show the greatest variability in this area, due to the greater number of technological factors that could be affected. Even for these vehicles, the 5-cycle fuel economy for the vehicle reflecting the greatest difference in temperature sensitivity was only changed 1%.

Regarding fuel consumption associated with a cold start, the primary issue is the assumption that the vehicle is fully warmed up by the end of Bag 1 of the FTP. We are not aware of any evidence that this is not the case at 75°F. As discussed in section III.A.4 above, there is some evidence that the vehicle is still warming up after Bag 1 at 20°F. However, if some of the difference between Bag 2 fuel consumption at 20°F and 75°F was due to continued vehicle warm up, then the difference after the vehicle was fully warmed up would be commensurately smaller. In general, the second change would tend to mitigate the first. We assessed the sensitivity of 5-cycle city fuel economy to just the first change by assuming that the difference in fuel consumption (in gallons) between Bag 2 at 20°F and 75°F was associated with the cold start. Doing so decreased 5-cycle fuel economy on average for non-hybrid vehicles by 0.16 mpg, or 1%. City fuel economy was reduced by 1.9 mpg for hybrids, or 5.7%. Reducing the impact of cold temperature on running fuel use would reduce this impact. As discussed in section III.E.5 below, reducing the incremental running fuel use at 20°F by 60% would increase city fuel economy for non-hybrid vehicles by 0.7% and by 4.5% for hybrids. Thus, the net effect of this shift of fuel use from running fuel use to start fuel use is to decrease city fuel economy by 0.3% for non-hybrids and 1.2% for hybrids.

One additional uncertainty regarding cold start fuel consumption involves the testing of hybrids. Most current hybrid designs include a sizeable battery with which to store energy from braking, provide launch power after extended idles, etc. Current EPA test procedures require that hybrids undergo a four-bag FTP, the fourth bag being a repeat of Bag 2. The state of battery charge is required to be the same at the beginning of the FTP and the end of the four bags. However, the state of battery charge need not be the same at the beginning and end of Bag 1, nor the beginning and end of Bag 3. Thus, the possibility exists that a portion of the difference in fuel consumption between Bags 1 and 3 is related to a change in battery charge, which may not occur on the road. One contributing factor towards this possibility is the fact that the driving pattern of Bags 1 and 3 is not representative of driving immediately following an engine start.[40] The speeds of the second hill in Bags 1 and 3 contain too much high speed driving. This affects the rate of engine warm-up for all vehicles. But it could also affect the net change in battery charge of hybrids relative to that occurring on the road.

As was the case with potential vehicle warm up during Bag 2, any difference in battery use between Bags 1 and 3 should reverse in Bags 2 and 4. Thus, if the indicated cold start fuel use is unrepresentatively high or low, the change in running fuel use should be in the opposite direction. Given the difference in trip length and bag weights between the FTP and the 5-cycle city formula, the opposing differences do not necessarily balance exactly. However, the net effect is likely to be much smaller than the effect of a change in battery charge on cold start fuel use.

We examined the potential impact of a change in battery capacity in Bag 1 relative to Bag 3 using two hybrids in our 5-cycle fuel economy database: a Honda Civic hybrid and a Toyota Prius. In both cases, we subtracted 0.005 gallons per mile from the fuel consumption in Bag 1 added the same fuel consumption to Bag 2. This was an increase in Bag 1 fuel consumption of 23-25% increase for the two vehicles. Thus, these are significant shifts in battery storage and probably exceed any change actually occurring during the FTP. This shift in fuel consumption increased the 5-cycle city fuel economy of the Civic by 0.5 mpg, or 1.5%. It increased the 5-cycle city fuel economy of the Prius by 1.0 mpg, or 2%. These changes in city fuel economy are likely worse case, since the degree of shift in fuel consumption are large percentages of Bag 1 fuel consumption. Also, such a shift in Bag 1 fuel consumption would likely produce some degree of shift in Bag 3 fuel consumption, as well. The above analysis assumed that Bag 3 fuel consumption remained unchanged. Still, the potential for change in battery charge status during Bags 1 and 3 could have a significant effect on 5-cycle city fuel economy values that may not reflect onroad operation. Without actual measurement of the state of battery charge after each bag of the FTP and on-road following vehicle start-up, it is not possible to quantify this uncertainty any further.

Regarding the effect of average trip length on start fuel consumption, the three studies with the most extensive collections of data were addressed in section I.A above: the instrumented vehicle studies conducted in support of the Supplemental FTP rule, the National Household Travel Study (NHTS), and the data currently being collected by Georgia Tech in Atlanta. One obvious uncertainty in the current estimates of average trip length is the 11% downward adjustment to the average trip length found in the NHTS. This reduction in average trip length from 9.8 to 8.7 miles was applied in order to obtain consistency with the results of the various instrumented vehicle studies performed in support of the Supplemental FTP rule and Atlanta. It is also based on the belief that instruments more accurately measure short trips and short respites between trips, such as moving a car out of the garage or stopping to refuel. Even if it is almost certain that a diary-based measure of trip length should be adjusted downward, the degree of this adjustment is uncertain. There is also uncertainty in the average trip length for urban dwellers, since only three cities have been studied with vehicle instrumentation.

In order to assess the potential consequence of this uncertainty, we removed the 11% adjustment from the national average trip length, leaving it at 9.8 miles. Retaining a highway trip length of 60 miles, this increased the city trip length to 4.6 miles. Using 4.6 miles for the average trip length for city driving increased the average fuel economy of the 615 vehicles in our 5-cycle fuel economy database from 16.9 mpg to 17.0 mpg, or by less than 1%. The 5-cycle city fuel economy of non-hybrids increased from 16.5 mpg to 16.6 mpg, while that for hybrids increased from 33.0 mpg to 33.2 mpg. These increases are quite small, particularly given the fact that this represents removal of the entire adjustment. Since the uncertainty in the 11% adjustment is likely much less than ±11%, the uncertainty is average trip length is not a major factor causing uncertainty in the 5-cycle fuel economy formulae.

Finally, we are promulgating a change in the test procedure of the Cold FTP which involves activation of the heater or defroster during the test. The vast majority of drivers obviously utilize their heaters at 20°F, but the number that do so between 20°F and 75°F has not been studied. The weighting factor for cold start fuel use was developed from test data which did not involve heater or defroster activation. Thus, consideration of the effect of heater/defroster use at various temperatures could affect this factor. Also, drivers can differ in the way they activate their heater and defroster at colder temperatures. As described in Section III.B. above, EPA has tested several vehicles at 20°F with and without heater/defroster activation. The impact on conventional vehicle start fuel use is minimal, decreasing 5-cycle city fuel economy by only 0.1%. Thus, the uncertainty in this effect as estimated in the 5-cycle formulae should be even smaller, given some heater and defroster use obviously occurs.

The effect is larger for hybrid vehicles, though it should be noted that our estimate of the effect is only based on the test results from two hybrid vehicles. Actual label values developed using the 5-cycle formulae will be based on actual Cold FTP fuel economy values measured with the heater/defroster activated. Removing the estimated effect of heater and defroster use from Bags 1 and 3 increases 5-cycle city fuel economy by 1%. The uncertainty in this effect as estimated in the 5-cycle formulae should be even smaller, given some heater and defroster use obviously occurs. Thus, even uncertainty in the effect of heater/defroster use on start fuel use does not appear to be a major source of uncertainty in 5-cycle city fuel economy.

2. Running Fuel Use At 75°F

In this section we evaluate several alternative approaches to determining the weighting of the various test cycles to estimate running fuel use at 75°F. One alternative evaluates a more ideal split of the US06 cycle into city and highway driving. In this case, both the second and third hills described in Table III.A-16 are designated as highway driving. The average speed of the US06 city bag decreases and the average speed of the US06 highway bag increases.

A second alternative eliminates the three highest speed freeway cycles which were not derived from the 3-city studies performed in support of the Supplemental FTP rule. These three cycles had to be developed subsequent to these instrumented vehicle studies due to the increase in maximum speed limit from 55 mph nationwide to 70 mph and even higher today. The basis for these three higher speed cycles is not as robust as that for the other 13 facility cycles. Thus, there is more uncertainty in the VSP distributions of these three highest speed cycles than the others.

A third alternative, actually a set of alternatives, evaluates the use of alternative fuel rates by VSP bin in the regression of dynamometer cycles versus onroad operation. Fuel rates from the EPA 15 car study, fuel rates from Draft MOVES2004 extrapolated to 23 VSP bins are substituted for those found in the EPA Kansas City testing. The impact of using just the 17 VSP bins current in Draft MOVES2004 is also evaluated.

A fourth alternative develops test cycle combinations which represent onroad VSP distributions and fuel rates from EPA's recent test program in Kansas City. Test cycle combinations are developed for non-hybrid and hybrid vehicles separately, given that significant numbers of both vehicle types were tested.

A final alternative develops a set of cycle weighting factors using only entire test cycles (FTP, HFET and US06) instead of allowing separate bag weights within the FTP and US06 cycles.

These alternatives and their effect on the cycle weighting factors are described below.

a. Alternative Definition of US06 City and Highway Bags

In section III.A.2, we defined the city bag of US06 to include hills number 1, 2, 4, and 5. However, hill 2 was placed in the city bag for practical, testing related reasons. Here, we redefine the city bag in a more ideal way to only include hills 1, 4, and 5. The highway bag includes hills 2 and 3. The description of the various hills in US06 and their assignment to the city and highway bags of US06 are shown in Table III.E-2.

Table III.E-2. Split of US06 Cycle into City and Highway Portions

Hill	Portion of Driving Cycle (cumulative seconds)	Maximum Speed (mph)	Proposed Designation	Ideal Designation
1	0-43	44.2	City	City
2	44-131	70.7	City	Highway
3	132-495	80.3	Highway	Highway
4	496-563	29.8	City	City
5	564-600	51.6	City	City

With this revised split, the average speed of the city bag decreases to 18.1 mph and the average speed of the highway bag increases to 80.3 mph. Table III.E-3 shows the VSP distributions for both the proposed and more ideal city and highway bags of US06.

Table III.E-3. VSP Distributions for US06 City and Highway Bags (% of time)

VSP Bin	Proposed Definition		More Ideal Definition	
	US06 City	US06 Hwy	US06 City	US06 Hwy
0	32.6%	7.1%	31.8%	11.9%
1	14.3%	2.5%	19.6%	3.5%
11	1.3%	0.3%	1.4%	0.4%
12	1.7%	0.3%	2.7%	0.2%
13	0.9%	0.0%	1.4%	0.0%
14	1.3%	0.0%	2.0%	0.0%
15	0.4%	0.0%	0.7%	0.0%
16	2.2%	0.3%	2.7%	0.4%
17	2.2%	0.0%	2.0%	0.4%
18	1.3%	0.0%	1.4%	0.2%
19	3.5%	0.5%	5.4%	0.4%
21	3.3%	0.3%	5.2%	0.2%
22	1.5%	0.1%	2.3%	0.1%
23	1.7%	0.1%	2.7%	0.1%
24	0.2%	0.0%	0.4%	0.0%
25	1.1%	0.0%	1.6%	0.0%
26	0.4%	0.0%	0.7%	0.0%
27	1.5%	0.1%	2.5%	0.1%
28	2.4%	0.4%	2.3%	0.7%
29	9.1%	1.6%	9.5%	2.9%
33	4.6%	9.9%	1.4%	10.5%
35	3.7%	20.7%	0.0%	19.2%
36	0.4%	13.8%	0.0%	11.4%
37	0.9%	16.2%	0.0%	13.4%
38	0.9%	10.2%	0.0%	8.5%
39	6.5%	15.5%	0.7%	15.1%

As can be seen from Table III.E-3, the changes in the VSP distribution of the highway bag changes are slight. This is due to the fact that hill 2 is much shorter than hill 3, so its addition has a smaller impact. Also, the driving in hills 2 and 3 are similar. However, the VSP distribution of the city bag changes dramatically. This occurs because hill 2 varies dramatically from hills 1, 4, and 5. In particular, the amount of time spent in VSP bins 33-39 decreases from 17% to 2%.

We repeated the regressions of the VSP distributions of the dynamometer bags and cycles (Tables III.A-15 and III.E-3) against the VSP distributions of city and highway driving (Table III.A-14) weighted by the square root of the fuel rate in each VSP bin from the Kansas City test program (Table III.A-16). The results using both sets of definitions of US06 city and highway bags are described in Table III.E-4 below.

Table III.E-4. Bag/Cycle Combinations for City and Highway Driving: Alternative US06 Splits

	Proposed Split	Ideal Split
City Driving		
Bag 2 FTP	48%	49%
Bag 3 FTP	41%	43%
US06 City	11%	8%
Highway Driving		
HFET	21%	17%
US06 Highway	79%	83%

As seen in Table III.E-5, the more ideal breakdown of the US06 cycle results in the same bags and cycles being selected to represent city and highway driving as use of the proposed split of US06. The contribution of the US06 city bag to city driving decreases slightly, while contribution of the US06 highway bag to highway driving increases slightly.

We reanalyzed the results of the 80 vehicles tested over US06 on a second by second basis in order to re-estimate the relative fuel economy over the US06 city and US06 highway bags using the more ideal split. We found that the fuel economy over the more ideal US06 city bag was only 50% of that over the entire US06 cycle, compared to 68% for the proposed US06 city bag. The fuel economy over the more ideal US06 highway bag was only 111% of that over the entire US06 cycle, compared to 116% for the proposed US06 highway bag. Thus, hill 2 appears to have a somewhat mid-range fuel economy compared to the lower speed hills 1, 4, and 5 and to the higher speed hill 3.

Using these revised cycle combinations and the revised estimates of US06 city and highway fuel economy relative to US06 fuel economy, we recalculated 5-cycle fuel economy estimates for the 615 vehicles in our 5-cycle fuel economy database. The results are summarized in Table III.E-5.

Table III.E-5. Average 5-Cycle Fuel Economy: Alternative US06 Splits

	Proposed US06 Split	Ideal US06 Split
City Fuel Economy (mpg_	16.9	16.7
Highway Fuel Economy (mpg)	23.1	22.1

As can be seen, 5-cycle city fuel economy decreases slightly, by roughly 1%. However, highway fuel economy decreases by 4.5%. This decrease in both city and highway fuel economy would increase the non-dynamometer factor by roughly 3%. Thus, the net change in city fuel economy would be an increase of roughly 1% and highway fuel economy would decrease by 1.5%.

b. Elimination of Three Highest Speed Freeway Cycles in Draft MOVES2004

As described in section III.A-2, Draft MOVES2004 uses 16 facility driving cycles to describe onroad driving. Most of these cycles are based on the results of the instrumented vehicle studies conducted in the early 1990's in support of the Supplemental FTP rule. However, since the maximum speed limit at this time was 55 mph and is now much higher, additional high speed cycles had to be developed to describe this now common type of driving.

During the development of MOBILE6.2, EPA developed three higher speed freeway cycles (High Speed Freeway 1, High Speed Freeway 2, and High Speed Freeway 3 in Table III.A-12). High Speed Freeway 3, the fastest of the three cycles, was based on a segment of onroad driving of one of the vehicles tested in the EPA 15-car study.[17] While this driving segment was actually driven on the highway by a vehicle, the EPA 15-car study was a pilot study and neither the vehicle nor driver selection was designed to be random. Also, since the drivers were either EPA employees or contractors and were aware of the purpose of the study, the driving was not designed to be representative of typical vehicle use. The portion of onroad driving represented by High Speed Freeway 3 is based on its average speed and onroad speeds predicted by travel demand models and California rural chase car data, the acceleration rates are not. Thus, the power demands of this cycle could differ from those on the road. The representativeness of the specific speed-time trace of High Speed Freeway 3 and its effect on vehicle power is being evaluated as part of the further development of MOVES.

The High Speed Freeway 2 cycle is a portion of the US06 cycle. This portion of the cycle met the desired average speed, which was slightly below that of High Speed Freeway 3. As discussed in section III.A.2, the US06 cycle is a concentrated version of the REP05 cycle. REP05 is a driving cycle which is representative of higher speed and/or higher power driving found onroad during the vehicle studies performed in support of the EPA Supplemental FTP rulemaking.[12] In the early 1990's, it represented roughly 28% of U.S. driving. US06, consisting of the most aggressive portions of REP05, represented a smaller percentage of driving at that time. However, both speed limits and the power to weight ratio of vehicles have both increased since that time. US06 driving represents more driving today than it did in the early 1990's. However, the exact percentage is not known. As is the case with High Speed Freeway 3, the portion of onroad driving represented by High Speed Freeway 2 is based on its average speed and onroad speeds predicted by travel demand models and California rural chase car data. However, the power demands of the cycle derive from the specific portion of US06 which was selected to comprise High Speed Freeway 2. Thus, the power demands of this cycle could differ from those of in-use vehicles which are driving at these speeds. The representativeness of the specific speed-time trace of High Speed Freeway 2 and its effect on vehicle power is being evaluated as part of the further development of MOVES.

High Speed Freeway 1 is the most representative of the three highest speed cycles.[41] It was developed for use in MOBILE6.2 from data obtained during the 3-city studies. Basically, vehicle operation which occurred on relatively uncongested freeways (LOS A-C) which lasted at least 30 seconds with a minimum speed of 50 mph were binned and used to create the High Speed Freeway 1 cycle. Thus, the underlying driving characteristics reflect real world operation in the early 1990's. However, vehicles operating at these speeds today might be driven differently, due to a change in the types of roadways which carry vehicles at these speeds and to the fact that many vehicles on the same roads are driving faster and not slower. As is the case with High Speed Freeway 2 and 3, the representativeness of the specific speed-time trace of High Speed Freeway 1 and its effect on vehicle power is being evaluated as part of the further development of MOVES.

We evaluated the impact of these three cycles on the proposed cycle combinations in the 5-cycle formulae by shifting the onroad driving assigned to these cycles to the fourth highest speed cycle, LOS AC Freeway. This is an extreme change and goes far beyond any possible uncertainty related to these three high speed freeway cycles. Thus, it bounds the potential uncertainty in this area and likely over-estimates it. Only the highway fuel economy formula is affected, since we assumed in section III.A.2 that 100% of the driving over these cycles was highway driving. As shown in Table III.A-13, this shift represents 20% of onroad highway like driving.

We repeated the regressions of the VSP distributions of the dynamometer bags and cycles (Tables III.A-15) against the VSP distribution of highway driving (Table III.A-14 with shift to LOS A-C Freeway) weighted by the square root of the fuel rate in each VSP bin from the Kansas City test program (Table III.A-16). The results with and without the three highest speed cycles are described in Table III.E-6 below.

Table III.E-6. Bag/Cycle Combinations for Highway Driving: High Speed Freeway Cycles

	With 3 High Speed Cycles	Without 3 High Speed Cycles
HFET	21%	25%
US06 Highway	79%	75%

Using this revised cycle combination for highway driving, we recalculated 5-cycle highway fuel economy estimates for the 615 vehicles in our 5-cycle fuel economy database. Eliminating the three highest speed freeway cycles increased average 5-cycle highway fuel economy from 23.1 mpg to 23.3 mpg, or by less than 1%.

c. Alternative Fuel Rates and Number of VSP Bins

In this section, we evaluate the use of three sets of alternative fuel rates by VSP bin in the regression of dynamometer cycles versus onroad operation. The three sets of fuel rates are based on: 1) the EPA 15 car study, 2) Draft MOVES2004 extrapolated to 26 VSP bins using fuel rates from the EPA 15 car study, and 3) Draft MOVES2004 extrapolated to 26 VSP bins using fuel rates from the EPA Kansas City testing. We also evaluate the impact of using just the 17 VSP bins currently used in Draft MOVES2004. In this case, the fuel rates are those currently in Draft MOVES2004.

These three sets of 26 VSP bin fuel rates were presented in Table III.A-16 above. Those currently in Draft MOVES2004 are simply those rates shown in Table III.A-16 under either of the "Extrapolated MOVES" columns for bins 0-16, 21-26 and 33-36. The 17 bin VSP distributions for both the dynamometer cycles and bags and the MOVES facility cycles are the same as those with 26 bins, except that the x6 bin contains all of the driving in bins x6, x7, x8 and x9.

We repeated the regressions of the VSP distributions of the dynamometer bags and cycles (Tables III.A-15) against the VSP distributions of city and highway driving (Table III.A-14) weighted by the square root of the various fuel rates. The results under the base case and the alternatives are shown in Table III.E-7 below.

Table III.E-7. Bag/Cycle Combinations for City and Highway Driving: Alternative Fuel Rates

	Base Case: Kansas City Fuel Rates	EPA 15 Car Fuel Rates	Extrapolated MOVES		MOVES 17 bin
			EPA 15 Car	Kansas City	
City Driving					
Bag 2 FTP	48%	50%	50%	50%	50%
Bag 3 FTP	41%	50%	50%	50%	39%
US06 City	11%	0%	0%	0%	11%
Highway Driving					
HFET	21%	21%	21%	21%	20%
US06 Highway	79%	79%	79%	79%	80%

As seen in Table III.E-7, the three alternative sets of fuel rates yield cycle combinations of city driving which are identical and do not include the US06 city bag. The MOVES 17 bin approach yields a cycle combination of city driving which is much more similar to that of the base case. Regarding the cycle combinations of highway driving, all of the various alternatives produce essentially identical results.

The results for city driving indicate that the contribution of the US06 city bag is the most uncertain of the 3 bags. This is confirmed by the p-values for the various bags in the final regressions. While the inclusion of the US06 city bag in the regression improves the adjusted r-squared value, the p-values for the US06 city bag are the highest of the three remaining bags, falling in the range of 0.2-0.3.

Using the 50/50 combination of bag 2 and 3 (zero weight for US06 city), we recalculated 5-cycle fuel economy estimates for the 615 vehicles in our 5-cycle fuel economy database. The 50/50 combination of Bags 2 and 3 increases 5-cycle city fuel economy for conventional vehicles from 16.5 mpg to 17.2 mpg, or by 4%, compared to the proposed cycle combination. The 50/50 combination of Bags 2 and 3 increases 5-cycle city fuel economy for hybrid vehicles from 33.0 mpg to 34.8 mpg, or by 5.5%, compared to the proposed cycle combination. The increase in city fuel economy also increases combined fuel economy by 2% for conventional vehicles and 3% for hybrids. This increase in combined 5-cycle fuel economy would lead to a lower factor for non-dynamometer effects, roughly decreasing from 0.905 to 0.885. This change would decrease both 5-cycle city and highway fuel economy by 2%. The uncertainty related to the contribution of the US06 city bag to city driving is the sum of the change in city fuel economy plus the change in both city and highway fuel economy due to a lower non-dynamometer factor. Thus, this uncertainty is roughly 2% in both city and highway fuel economy for conventional vehicles and 4% for city and 2% for highway fuel economy for hybrid vehicles.

d. Kansas City VSP Distributions and Fuel Rates

EPA's recent testing of roughly 100 recent model year vehicles in Kansas City is described in detail in Appendix A. We aggregated the driving activity and fuel rates measured during this testing (basically one day's driving for each vehicle) and developed VSP distributions and average fuel rates by VSP bin for two sets of vehicles, conventional vehicles and hybrids. In order to develop VSP distributions for city and highway driving, we segregated driving activity on a second by second basis into two groups: those at 45 mph or lower and those above 45 mph. This segregation is not exactly consistent with our definition of city and highway driving, since these are based on longer time frames than one second. However, this was the only method applicable in the near term. With additional time, each vehicle's driving trace could be reviewed visually and segregated into city and highway driving. We may attempt to do this in the future.

The city and highway VSP distributions and fuel rates are shown in Table III.E-8.

Table III.E-8. Kansas City VSP Distributions and Fuel Rates

VSP Bin	VSP Distribution: Non-Hybrids		VSP Distribution: Hybrids		Fuel Rate (g/sec)	
	City	Highway	City	Highway	Non-Hybrids	Hybrids
0	8.4%	0.8%	9.7%	0.7%	0.412	0.097
1	29.1%		10.6%		0.384	0.248
11	5.5%		7.5%		0.454	0.122
12	9.7%		13.7%		0.641	0.188
13	3.5%		4.9%		1.122	0.466
14	2.1%		2.5%		1.406	0.690
15	1.6%		2.0%		1.715	0.857
16	0.7%		0.8%		2.006	0.976
17	0.4%		0.4%		2.172	1.126
18	0.2%		0.1%		2.358	1.182
19	0.2%		0.0%		2.296	1.319
21	7.3%	1.8%	9.5%	1.8%	0.593	0.225
22	8.8%	0.1%	16.8%		0.833	0.359
23	9.7%	3.6%	6.9%	5.4%	0.986	0.578
24	2.8%	1.9%	4.8%		1.180	0.569
25	4.0%	0.0%	4.9%		1.352	0.755
26	2.5%	1.0%	2.4%	1.8%	1.631	0.993
27	1.0%	1.0%	1.1%	0.2%	1.917	1.107
28	0.8%	0.0%	0.7%	0.5%	2.272	1.327
29	1.6%	0.7%	0.6%	0.5%	2.424	1.588
33		14.5%		19.2%	1.069	0.645
35		36.8%		49.8%	1.486	0.920
36		15.7%		6.9%	1.753	1.175
37		6.5%		3.9%	1.937	1.160
38		4.5%		3.6%	1.948	1.210
39		11.2%		6.1%	2.309	1.441

We repeated the regressions of the VSP distributions of the dynamometer bags and cycles (Tables III.A-15) against the VSP distributions of city and highway driving weighted by the square root of the various fuel rates shown in Table III.E-8. The results for the base case and the two vehicle types in Kansas City are shown in Table III.E-9 below.

Table III.E-9. Bag/Cycle Combinations for City and Highway Driving: Kansas City

	Base Case	Kansas City Non-Hybrids	Kansas City Hybrids
City Driving			
Bag 2 FTP	48%	39%	70%
Bag 3 FTP	41%	61%	30%
US06 City	11%	0%	0%
Highway Driving			
HFET	21%	38%	56%
US06 Highway	79%	62%	44%

The cycle combinations for non-hybrid and hybrid vehicles tested in Kansas City vary dramatically from those of the base case and from each other. The US06 city bag does not appear in either of the final regressions for city driving in Kansas City. However, Bag 3 dominates city driving by non-hybrids, while Bag 2 dominates city driving by hybrids. The potential causes for this difference in the driving of hybrids and conventional vehicles are discussed in some detail in Appendix A. First, this difference is based on limited driving; roughly one hour of driving per vehicle. Second, while it is possible that this difference, if real, will persist in the future, it seems more likely that any difference will disappear as more high power hybrids enter the fleet and more drivers purchase hybrids.

The contribution of the US06 highway bag to highway driving in Kansas City is also lower than that predicted by MOVES for both vehicle types. The contribution of the US06 highway bag to highway driving by hybrids in Kansas City is also lower than that by conventional vehicles. A more detailed review of the regression results for highway driving indicates that the model is having difficulty in matching the onroad VSP distributions for highway driving. In all the other regressions of highway driving, the coefficients for HFET and US06 highway from the raw regression results sum very close to 1.0 (e.g., 0.97). In Kansas City, the coefficients for HFET and US06 highway from the raw regression results sum to roughly 1.25. Mathematically, this means that in order to minimize error, the model wants to use 1.25 seconds of cycle driving to match the fuel consumption of one second of onroad driving. This means that the normalized coefficients presented in Table III.E-8 will under-estimate onroad fuel consumption significantly. The prediction of relative fuel consumption across models might be reasonable for the highway driving performed in Kansas City, but the absolute prediction will be quite low. This would necessitate use of a non-dynamometer factor well below 1.0, as opposed to the 0.98 factor proposed in section III.A-5.

In general, a sum of coefficients well above or below 1.0 indicates that the model cannot match the onroad fuel consumption per second using the cycles made available to it. In the case of highway driving, the model would normally increase the contribution of US06 highway, as this cycle has higher average fuel consumption than HFET. However, this is creating too great an error in the individual VSP bins and the sum of squared errors increases. This means that the highway driving observed in Kansas City differs dramatically (in terms of VSP) from both the HFET and US06 highway cycles and that another cycle is needed.

As will be seen in the next section, driving observed in California yield very different cycle combinations compared to those based on the Kansas City data. This indicates the need for driving to be characterized in a number of urban areas in order to be representative of the country as a whole, and not based on just one or two areas.

e. California Chase Car Studies

As described in Appendix A, Sierra Research has performed several chase car studies of both urban and rural driving in California since 1998. We have not yet been able to perform a detailed analysis of the second by second data from this testing. However, we have been able to develop approximate VSP distributions for urban and rural driving from the speed-acceleration frequency distributions. As in Kansas City, we assumed that driving at or below 45 mph was city driving and driving above 45 mph was highway driving. However, one of the SAFD bins was centered at 45 mph (i.e., speeds of 42.5-47.5 mph). This bin was assigned to city driving. Also, all driving in bins 17-19 were assigned to bin 16. These VSP distributions are shown in Table III.E-10.

Table III.E-10. California Urban and Rural VSP Distributions

VSP Bin	Urban		Rural		Fuel Rate (g/sec)	
	City	Highway	City	Highway	Non-Hybrids	Hybrids
0	16.3%	2.9%	19.8%	2.2%	0.412	0.097
1	14.9%	0.0%	6.8%	0.0%	0.384	0.248
11	4.9%	0.0%	2.8%	0.0%	0.454	0.122
12	14.6%	0.0%	9.3%	0.0%	0.641	0.188
13	5.3%	0.0%	3.5%	0.0%	1.122	0.466
14	4.6%	0.0%	3.0%	0.0%	1.406	0.690
15	3.9%	0.0%	3.1%	0.0%	1.715	0.857
16	2.8%	0.0%	4.4%	0.0%	2.006	0.976
21	5.2%	2.6%	6.4%	1.9%	0.593	0.225
22	4.0%	0.0%	2.4%	0.0%	0.833	0.359
23	12.2%	0.0%	18.1%	0.0%	0.986	0.578
24	2.1%	8.6%	1.2%	7.4%	1.180	0.569
25	2.1%	0.0%	1.9%	0.0%	1.352	0.755
26	4.4%	0.0%	8.9%	0.0%	1.631	0.993
27	0.8%	3.2%	1.8%	2.6%	1.917	1.107
28	0.9%	0.0%	2.9%	0.0%	2.272	1.327
29	0.9%	0.7%	3.8%	0.6%	2.424	1.588
33	0.0%	12.1%	0.0%	9.6%	1.069	0.645
35	0.0%	19.8%	0.0%	27.0%	1.486	0.920
36	0.0%	14.7%	0.0%	11.3%	1.753	1.175
37	0.0%	13.4%	0.0%	11.8%	1.937	1.160
38	0.0%	8.7%	0.0%	11.5%	1.948	1.210
39	0.0%	13.2%	0.0%	14.1%	2.309	1.441

We repeated the regressions of the VSP distributions of the dynamometer bags and cycles (Tables III.A-15) against the VSP distributions of California city and highway driving in urban and rural (Table III.E-10) weighted by the square root of the Kansas City fuel rates (Table III.A-16). We performed the same analysis for combined urban/rural VSP distributions of city and highway driving, using an urban/rural weighting of 60/40 (consistent with FHWA estimates of urban and rural VMT for the U.S.). The chase car studies showed that 75.5% of all urban operation was city driving and 24.5% was highway. In contrast, 30.4% of all rural operation was city driving and 69.6% was highway. Thus, the VSP distribution for combined urban/rural city driving was developed by weighting the urban city driving VSP distribution by 78.8% and the rural city driving VSP distribution by 21.2%. Likewise, the VSP distribution for combined urban/rural highway driving was developed by weighting the urban highway driving VSP distribution by 34.5% and the rural city driving VSP distribution by 65.5%. The results for the base case and the California cases are shown in Table III.E-11 below.

Table III.E-11. Bag/Cycle Combinations for City and Highway Driving: California

	Base Case	California Urban	California Rural	All California
City Driving				
Bag 2 FTP	48%	42%	0%	35%
Bag 3 FTP	41%	42%	75%	46%
US06 City	11%	16%	25%	19%
Highway Driving				
HFET	21%	13%	21%	18%
US06 Highway	79%	87%	79%	82%

Overall, the dynamometer cycle combinations for California driving tend to be more aggressive than those based on Draft MOVES2004 and are decidedly more aggressive than those found in Kansas City. City driving in California shows a 16-19% contribution for the US06 city bag, versus 11% based on Draft MOVES2004 and zero in Kansas City. Highway driving in California shows a 79-87% contribution for the US06 highway bag, versus 79% based on Draft MOVES2004 and 44% for hybrids and 63% for non-hybrids in Kansas City. Chase car studies can tend to under-represent driving on neighborhood and local roads. Thus, some increased percentage of US06 city driving can be expected in the cycle combinations for city driving. However, one would not expect over-estimation by a factor of two. The characterization of highway driving should not be affected by this factor, since vehicle speeds on local and neighborhood roads tend to be less than 45 mph.

Thus, the results from Kansas City and California indicate the need for driving to be characterized in a number of urban areas in order to be representative of the country as a whole. The cycle combinations based on Draft MOVES2004 fall in between those found in Kansas City and California and thus, are not inconsistent with the driving in the two specific geographical areas.

f. Alternative Splits of City/Highway Driving

In Sections III.A.1 and III.A.2, we define city driving as that below 45 mph and highway driving as that above 45 mph. According to this definition, we assigned all of the driving over the LOS D Freeway cycle to highway driving. This definition of city and highway driving produces a city/highway VMT split of 43/57, which differs dramatically from the current 55/45 split. We believed it appropriate to investigate some options which yielded city/highway VMT splits closer to the current split of 55/45, specifically 50/50 and 55/45. This was accomplished by adjusting the split of driving over the LOS D freeway cycle to city and highway categories.

The LOS D freeway cycle has an average speed of 53 mph and over three-quarters of the driving time of this cycle is above 45 mph. However, the cycle does include some driving below 30 mph (about 3% in terms of driving time). Thus, there is some rationale to assigning at least a portion of this cycle to city driving. Also, the LA4 road route which is the basis for the FTP test included some freeway operation. Bag 3 of the FTP has a maximum speed of 55 mph and about 20% of the driving time during this bag is above 45 mph. All the cycle combinations representing city driving include Bag 3, so all these representations of city driving include some driving over 45 mph regardless of how city driving is defined with respect to the Draft MOVES2004 facility cycles. Thus, assigning some driving over 45 mph to city driving could improve the representation of city driving (i.e., increase the adjusted r-squared values in the regression of the VSP distribution of city driving versus those of the dynamometer cycles).

To assess this possibility, we developed two alternative assignments of driving of the LOS D Freeway cycle to city and highway driving. The first produced an overall city/highway VMT split of 50/50, while the second produced an overall city/highway VMT split of 55/45. The first split required assigning 26% of LOS D Freeway driving to city driving, while the second the required assigning 43% of LOS D Freeway driving to city driving. We recalculated the VSP distributions of city and highway driving with the two alternative assignments of LOS D Freeway driving. The base case and alternative VSP distributions are shown in Table III.E.12.

Table III.E-12. VSP Distributions for U.S. Driving with Alternative Definition of City Driving (% of time)

VSP Bin	Base: 43/57 City/Highway Split		50.50 City/Highway Split		55/45 City/Highway Split	
	City VSP	Highway VSP	City VSP	Highway VSP	City VSP	Highway VSP
0	11.8%	3.9%	11.4%	3.6%	11.1%	3.5%
1	20.4%	0.2%	19.1%	0.2%	18.3%	0.3%
11	8.3%	0.1%	7.8%	0.2%	7.5%	0.2%
12	13.0%	0.1%	12.1%	0.1%	11.7%	0.2%
13	6.0%	0.1%	5.6%	0.2%	5.4%	0.2%
14	3.5%	0.1%	3.3%	0.1%	3.1%	0.1%
15	2.2%	0.0%	2.0%	0.0%	2.0%	0.0%
16	0.6%	0.0%	0.5%	0.0%	0.5%	0.0%
17	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%
18	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
21	5.5%	2.8%	5.4%	2.5%	5.4%	2.3%
22	6.2%	2.9%	6.1%	2.5%	6.1%	2.3%
23	4.7%	3.2%	4.7%	2.8%	4.7%	2.5%
24	4.2%	2.9%	4.3%	2.6%	4.3%	2.3%
25	3.0%	2.6%	3.1%	2.4%	3.1%	2.1%
26	2.2%	2.4%	2.3%	2.2%	2.3%	1.9%
27	0.8%	0.9%	0.9%	0.8%	0.9%	0.8%
28	0.4%	0.5%	0.4%	0.4%	0.4%	0.4%
29	0.3%	0.9%	0.4%	0.9%	0.4%	0.8%
33	1.9%	16.7%	2.8%	16.7%	3.4%	16.7%
35	2.3%	21.0%	3.3%	21.5%	3.9%	21.9%
36	1.1%	10.1%	1.6%	10.2%	1.9%	10.3%
37	0.9%	9.8%	1.3%	10.2%	1.5%	10.5%
38	0.5%	8.0%	0.8%	8.4%	1.0%	8.7%
39	0.2%	10.7%	0.6%	11.4%	0.8%	11.9%

Shifting some of the driving over the LOS D Freeway cycle to city driving increases operation in Bins 33-39 significantly in the VSP distribution for city driving. It also increases operation in Bins 35-39 and reduces operation in Bins 21-29 in the description of highway driving.

We repeated the regressions of the VSP distributions of the dynamometer bags and cycles (Tables III.A-15) against the alternative VSP distributions of city and highway driving shown in Table III.E-12 weighted by the square root of the Kansas City fuel rates (Table III.A-16). As has been done in all such regressions, we first dropped those cycles or bags with negative coefficients and then dropped the least significant cycles or bags until the adjusted R-squared value decreased. Then, the results of the previous regression were selected as the final combinations of cycles. The results for the base case and the revised split of city and highway driving are shown in Table III.E-13 below.

Table III.E-13. Cycle Combinations for City and Highway Driving: Revised City/Highway Split

	Base Case		50/50 City/Highway Split		55/45 City/Highway Split	
	Cycle %	p-value	Cycle %	p-value	Cycle %	p-value
City Driving						
Bag 2 FTP	48%	<0.001	40%	<0.001	35%	<0.001
Bag 3 FTP	41%	0.01	43%	0.003	43%	0.0015
US06 City	11%	0.26	0%	----	0%	----
US06 Highway	0%	----	17%	0.11	22%	0.034
Adjusted r-squared	0.7262		0.7048		0.6958	
Highway Driving						
HFET	21%	<0.001	20%	<0.001	18%	<0.001
US06 Highway	79%	<0.001	80%	<0.001	82%	<0.001
Adjusted r-squared	0.8682		0.8784		0.8855	

Including some operation over 45 mph in the definition of city driving has a significant effect on the cycles which represent city driving. For both alternative definitions of city driving, US06 city drops out of the cycle combination and US06 highway is added at roughly twice the previous US06 city weight. The contribution of Bag 2 drops, as well. These changes are progressive. The greater the percentage of city driving overall (i.e., the greater the percentage of LOS D Freeway driving assigned to city driving), the greater degree that the above changes occur. The effect on highway driving is much smaller: the weight of US06 highway increases 1-4%, while that of HFET decreases commensurately.

Some of the regression statistics appear to be better for the base definition of city driving, while others appear better for the higher city driving fraction. Again, the changes are progressive with respect to the two alternatives. The adjusted r-squared value for the base case combination of city driving is higher than that for either alternative definition of city driving. However, the p-values for the US06 bag with the alternative definitions of city driving are better than that for the base definition. The more high speed driving is included in city driving, the greater the significance of the US06 highway coefficient. With the base definition of city driving, including US06 city improves the adjusted r-squared value, but the p-value of the US06 coefficient is relatively high, 0.26.

For highway driving, the p-values for both HFET and US06 are very low in both cases. However, the adjusted r-squared value increases as the overall city driving fraction increases. In both alternative cases, the adjusted r-squared value is higher than that with the base definition of city driving.

The impact of increasing the VMT fraction of city driving on the 5-cycle fuel economy of the 615 vehicles in our certification database is shown in Table III.E-14. In addition to the revised cycle combinations shown in Table III.E-13, increasing the city fraction of VMT also increases the average trip length of city driving. For a city/highway VMT split of 50/50, the average trip length for city driving increases from 4.1 miles to 4.7 miles, while that for a split of 55/45 is 5.1 miles. The effect of this increased trip length is included in the 5-cycle fuel economy estimates with the 505/50 and 55/45 city/ highway VMT splits.

Table III.E-14. 5-Cycle Fuel Economy Values: Effect of the Definition of City Driving (mpg)

	City		Highway		Composite	
	Non-Hybrid	Hybrid	Non-Hybrid	Hybrid	Non-Hybrid	Hybrid
Current EPA Label	18.6	42.7	24.6	42.8	20.9	42.6
5-Cycle						
43/57 City/Hwy Split	16.5	33.0	22.8	36.9	19.6	35.0
50/50 City/Hwy Split	17.7	34.2	22.7	36.8	20.2	35.5
55/45 City/Hwy Split	17.9	34.0	22.6	36.6	20.3	35.4

Moving some of the operation over LOS D Freeway to city driving increases 5-cycle city fuel economy for both non-hybrids and hybrids. This is not surprising, given that fuel economy over the US06 city bag is the lowest of any of the dynamometer cycles or bags. The effect is again progressive with the degree of the shift of driving from highway to city. Five-cycle highway fuel economy decreases very slightly due to the increased fraction of US06 highway in the 5-cycle formula. Composite fuel economy increases slightly. This implies that the effect of higher city fuel economy is slightly greater than the effect of the increased city VMT fraction.

The ORNL Your MPG website, discussed in detail in section II.A, contains consumers estimates of their onroad fuel economy, as well as their estimate of their city and highway driving fractions. Across the 8180 estimates of fuel economy, the average percentage of city driving is 43%. This is closer to the 43% estimate resulting from placing all the operation over LOS D Freeway into the highway driving category than splitting this operation between city and highway driving. At the present time, it is the primary source of information about how typical drivers label their own driving.

g. Complete Cycles

A final set of alternatives develops cycle combinations using entire test cycles (FTP, HFET and US06) instead of allowing separate bag weights within the FTP and US06 cycles. One alternative investigates the impact of not splitting US06 into city and highway bags, but retaining separate bags for the FTP. The other alternative investigates the impact of not splitting US06 into city and highway bags, as well as using a combined Bag 2 plus Bag 3 fuel economy. The latter might be applicable to current hybrid testing. A hybrid FTP test consists of two complete LA4 driving cycles, one with a cold start and one with a hot start. This is often accomplished using four emission bags, with Bag 4 being similar to Bag 2. However, EPA regulations allow emissions to be measured in only two bags, Bag 1 consisting of the normal Bags 1 and 2 and Bag 2 consisting of the normal Bag 3 plus the extra Bag 4. In these cases, fuel economy measurements for each of the four bags would not be available.

We repeated the regressions of the VSP distributions of the dynamometer bags and cycles (Tables III.A-15) against the Draft MOVES2004 VSP distributions of city and highway driving (Table III.A-14) weighted by the square root of the Kansas City fuel rates (Table III.A-16). The results for the base case and the alternative complete cycle cases are shown in Table III.E-15 below.

Table III.E-15. Bag/Cycle Combinations for Complete Cycle Alternatives

	Base Case	Complete US06	Complete US06 and LA4
City Driving			
Bag 2 FTP	48%	50%	----
Bag 3 FTP	41%	50%	----
LA-4	----	----	100%
US06 City	11%	----	----
Highway Driving			
HFET	21%	25%	25%
US06 Highway	79%	----	----
US06	----	75%	75%

Not surprisingly, maintaining US06 as a single cycle eliminates any contribution of US06 to city driving. The weights of Bag 2 and Bag 3 become 50% each, as was the case for the alternative fuel rates in Table III.E-7. This is also consistent with the modeling of city driving under cold temperature conditions where the US06 city bag was not allowed in the regression. Maintaining US06 as a single cycle reduces the contribution of US06 to highway driving modestly.

The results are quite similar when the LA-4 cycle is substituted for Bags 2 and 3. The weighting of Bags 2 and 3 in the LA-4 is 52/48, which is very similar to the 50/50 weighting found when separate bag estimates are allowed into the model. The impact of using whole cycles on 5-cycle city and highway fuel economy values is shown in Table III.E-16.

Table III.E-16. Effect of Using Whole Cycles on 5-Cycle Fuel Economy Values (mpg)

	Conventional Vehicles		Hybrids	
	City	Highway	City	Highway
Current EPA label	18.6	24.6	41.6	40.6
Base Case 5-cycle	16.5	22.8	33.0	36.9
Complete US06 5-cycle	17.2	20.5	34.8	34.7
Complete US06 and LA4 5-cycle	17.2	20.5	35.0	34.7

As expected, eliminating the contribution of US06 city from the 5-cycle city formula increases city fuel economy (by about 4% in both alternative cases for conventional vehicles). While increasing the contribution of HFET increases highway fuel economy, shifting from US06 highway to the whole US06 cycle decreases fuel economy. The latter impact predominates and highway fuel economy decreases substantially (~10% for conventional vehicles). City fuel economy for hybrids is slightly more sensitive to these changes than conventional vehicles, while highway fuel economy is less sensitive. Hybrid city fuel economy increases 6%, while hybrid highway fuel economy decreases 6%.

3. Air Conditioning Effects

The primary factors affecting the estimation of fuel use related to air conditioning are: 1) the degree of compressor engagement during the SC03 test, 2) the degree of compressor engagement on the road, 3) the effect of vehicle speed on fuel use related to running the compressor, and 4) the effect of ambient conditions on the load of the compressor on the engine. The potential uncertainty in each of these factors and its affect on 5-cycle fuel economy will be addressed below.

We assume that every vehicle's air conditioning compressor is engaged 100% of the time during the SC03 test. This is based on general knowledge of the SC03 test itself. For example, the test only lasts 10 minutes and the vehicle is subjected to strong sunlight at 95°F during vehicle preconditioning operation (e.g., running a Bag 1 or 2 of the FTP, both Bags 1 and 2 of the FTP, a SC03 test) and during the ten minute soak prior to the test. The air conditioning system and fan are turned to its maximum setting and the recirculation option is chosen, if available.

EPA also made the same assumption when estimating the emission benefits associated with the SC03 emission standards.[42] It is clear from the description of various test programs performed in support of this rule that the engagement of the compressor was measured over the SC03 and other test cycles and that the Agency had this information when it assumed that the compressor was engaged 100% of the time over the SC03 test. However, this data is no longer easily accessible and the level of compressor use which was actually measured over these tests was not presented in any of the official rulemaking documents. Also, it is possible that vehicles' air conditioning system designs have changed since the early 1990's. The degree of compressor engagement over SC03 today might differ from that measured at that time. Therefore, in order to assess the possible uncertainty in this assumption, we assume here that the compressor is engaged only 80% of the time over SC03.

Reducing the amount of time that the compressor is engaged over SC03 from 100% to 80% can be modeled by simply dividing the incremental fuel use over SC03 versus the 69/31 mix of fuel use over Bags 3 and 2 of the FTP by a factor of 0.8. This change decreases the 5-cycle city fuel economy of non-hybrid vehicles from 16.5 mpg to 16.4 mpg and that for hybrids decreases from 33.0 mpg to 32.6 mpg. Thus, the change in city fuel economy is roughly 1%. The change in compressor engagement over SC03 affects highway fuel economy even less. Five-cycle highway fuel economy of non-hybrid vehicles decreases from 22.8 mpg to 22.7 mpg and that for hybrids decreases from 36.9 mpg to 36.7 mpg. Thus, the change in highway fuel economy is roughly half of one percent. Overall, the changes in both city and highway fuel economy are small.

Regarding the degree of compressor engagement on the road, the Phoenix study used to develop the 0.133 factor in the 5-cycle fuel economy formulae is based on the only instrumented vehicle study performed to date. As discussed above, the NREL-OAP model, based on a person's comfort at a given ambient temperature and humidity, yields an estimate of drivers turning on the air conditioning of 29%, versus that based on the Phoenix work of 24%. Considering the fact that the compressor is not always engaged when the air conditioning system is turned on, and the fact that the ambient temperature is usually less than 95 F, we estimate that the compressor is on 13.3% of the time at a load equivalent to that occurring at 95 F. The comparable percentage based on the NREL-OAP system-on estimate would be 16.1%. Defroster use, based on the NREL-OAP work, could add another 0.4% to overall compressor use (in terms of compressor load at 95°F). Thus, if both of the NREL-OAP estimates were correct, the 0.133 factor for compressor use in the 5-cycle formulae could be as high as 0.165. This increase is roughly equivalent to the increase associated with assuming that the compressor is only engaged 80% of the time over the SC03 test. Thus, the fuel economy effects of increasing the air conditioning usage factor to 0.152 would essentially the same as those just presented above (i.e., 1.0% for city fuel economy and 0.5% for highway fuel economy). These are very small changes.

Regarding the effect of vehicle speed on fuel use related to running the compressor, this uncertainty primarily applies to highway fuel economy. The speed of SC03 is within 10% of that for average city driving. So there is little uncertainty in applying the incremental fuel use of SC03 to city driving. The extrapolation to highway driving is much larger, the ratio of highway speeds to the speed over SC03 being a factor of 2.67. Our testing of six vehicles with the air conditioning on and off over the FTP, SC03 and HFET showed that the fuel use per unit of time tended to be within 10% over the various cycles. However, these tests were not conducted in an environmentally controlled test cell. Thus, further differences could occur under more realistic ambient conditions. Also, the HFET was the only highway cycle tested. The differences could be larger if, for example, vehicles would have been tested over the US06. Therefore, to assess the uncertainty in this factor, we assume here that the difference in fuel use per unit of time over the various cycles could vary by as much as 20%. This can be represented by applying an exponent of 0.8 to the ratio of speeds over the SC03 and highway driving. Thus, instead of a factor 0.366 (21.5 mph divided by 57.1 mph), the factor would be 0.458. With this change, highway fuel economy changed less than 0.5%. Therefore, this factor is not likely a significant source of uncertainty in the 5-cycle highway fuel economy formulae.

Finally, regarding the effect of ambient conditions on the load of the compressor on the engine, consideration of this factor reduces the effective compressor on time from 15.2% to 13.3%, or by a factor of 0.875. A reasonable estimate of the uncertainty in this factor would be to double its effect (i.e., double its difference from 1.0). This would mean reducing the factor to 0.75. This change increases city fuel economy from non-hybrid vehicles by 0.1 mpg and by 0.3 mph for hybrids, at most 1% in the latter case. The effect on highway fuel economy is even smaller, less than 0.5% in either case. Therefore, uncertainty in this area is unlikely to significantly affect 5-cycle fuel economy.

In all, uncertainty in the four factors affecting the impact of air conditioning on onroad fuel economy appears to be quite small. No single factor appears to affect fuel economy by more than 1%, with most being significantly less than this.

4. Cold Temperature Running Fuel Use

The primary factors affecting the impact of colder temperatures on fuel economy are: 1) the assumption that vehicles are fully warmed up by the end of Bag 1 of the FTP, 2) the effect of heater/defroster use on warmed up fuel use, 3) the use of fuel consumption over just Bags 2 and

3 to represent city driving and 4) the assumption that fuel consumption increases 4% during highway driving at 20°F.

The potential impact of the assumption that vehicles are fully warmed up by the end of Bag 1 of the FTP was addressed above in section III.E.1. As described there, if the vehicle continued to warm up during Bag 2 at 20°F relative to that at 75°F, cold start fuel use would increase and warmed up fuel use decrease. The net effect was an increase in the 5-cycle city fuel economy of conventional vehicles of 0.3% and 1.2% for hybrids.

As described in Section III.E.1, the effect of heater/defroster use is estimated to be very small for conventional vehicles, but more significant for hybrids. Some effect of heater/defroster use is certain, given the fact that most drivers use the heater and/or the defroster under certain conditions. However, given the absence of precise data on their use under specific ambient conditions, it is difficult to establish a precise uncertainty in their effect on onroad fuel economy as indicated by the 5-cycle formulae. An upper bound on the uncertainty is the overall impact of heater/defroster use on 5-cycle fuel economy. For conventional vehicles, removing the impact of the heater/defroster increases 5-cycle city fuel economy by 0.4%. There is no effect on 5-cycle highway fuel economy, as the effect of colder temperatures on running fuel use is modeled and not based on the Cold FTP test. For hybrids, the effect is roughly 4%. Since heater/defroster use clearly affects warmed up fuel use with current hybrid systems, some loss in onroad fuel economy is certain. Thus, the uncertainty in the 5-cycle city fuel economy due to this factor is likely well below 4%.

Regarding the absence of the US06 city cycle in the estimate of running fuel use at cold temperatures, this means that the driving cycles underlying our estimated fuel use at 75°F and 20°F are inconsistent to some degree. We developed three approaches to estimate the potential uncertainty associated with this difference. Each approach estimates the effect of cold temperature on running fuel use during city driving slightly differently. For review, the approach included in the final 5-cycle fuel economy formula bases running fuel use at 20°F only on Bags 2 and 3 of the FTP (Bags 3 and 4 for hybrids and other vehicles tested over a 4-bag FTP). Therefore, the effect of the US06 city cycle is included in the estimate of running fuel use at 75°F (using a weighting factor of 16%), but not at 20°F. The first alternative approach calculates the effect of including the US06 city cycle at 75°F and then applies this effect to the running fuel use at 20°F, which is based only on Bags 2 and 3 of the FTP. To do this, we first remove the effect of cold temperature completely. We then determined the impact of replacing the 11% weight of the US06 city cycle by increasing the weights of Bags 2 and 3 each by 5.5%. This replacement increased the city fuel economy from non-hybrid vehicles from 16.7 mpg to 17.5 mpg, or by 5%. Hybrid city fuel economy increased from 35.9 mpg to 38.6 mpg, or by 8%. With an 18% weighting factor for running fuel use at 20°F, this means that the current approach in this area could be under-estimating onroad fuel economy by 1% for non-hybrids and 2% for hybrids.

The second alternative approach assumes that the effect of cold temperature on running fuel use over Bags 2 and 3 of the FTP applies to all city driving, including the US06 city cycle. Therefore, under this approach, running fuel use at 75°F is estimated using the 43/41/16% weights for Bag 2, Bag 3 and US06 city cycles. Running fuel use at 20°F is equal to running fuel use at 75°F plus the difference in running fuel use over a 50/50% weight of Bags 2 and 3 at 20°F and 75°F. This approach yields the same effect as those of the first alternative approach. The city fuel economy of non-hybrid vehicles decreases by 1% and that for hybrids decreases by 2%.

The third and final alternative approach is similar to the second approach in that it assumes that the effect of cold temperature on running fuel use over Bags 2 and 3 of the FTP applies to all city driving, including the US06 city cycle. However, rather than calculating an effect of cold temperature in terms of an absolute difference in fuel consumption, it calculates a relative difference in percentage terms and applies this percentage to relative fuel consumption at 75°F. Therefore, under this approach, running fuel use at 75°F is estimated using the 43/41/16% weights for Bag 2, Bag 3 and US06 city cycles. Running fuel use at 20°F is equal to running fuel use at 75°F times the percentage increase in running fuel use over a 50/50% weight of Bags 2 and 3 at 20°F and 75°F. This approach yields roughly the same effect as those of the first and second alternative approaches. The city fuel economy of non-hybrid vehicles decreases by 1% and city fuel economy for hybrids decreases by 2%.

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Chapter IV: Economic Impacts

A. Testing and Facilities Burden

This section gives additional details for the Cost Analysis under Part VI. of the Preamble, "Projected Cost Impacts ."

The final rule requires calculation of fuel economy values based on the five-cycle formulae beginning with model year 2011 for some engine families. As discussed in detail elsewhere, for model years 2008 through 2010, manufacturers may use the mpg-based calculation for the five-cycle fuel economy values or they may conduct voluntary testing. For model year 2011 and after, if the five-cycle city and highway fuel economy values for an emission data vehicle group are within 4% and 5% of the mpg-based regression line, respectively, then all the vehicle configurations represented by the emission data vehicle (e.g., all vehicles within the vehicle test group) would use the mpg-based approach. Vehicles within a test group falling below the 5% tolerance band for highway fuel economy values would be required to conduct US06 tests; those falling below the city fuel economy band would be required to conduct SC03, US06, and Cold FTP tests. In addition, we expect that some of these vehicles falling below the tolerance levels may be eligible to estimate fuel economy for a given test through the application of analytically derived fuel economy (ADFE) values. Some data is currently available for vehicles that have conducted all five tests; based on this data, EPA has estimated the number of vehicles for which additional testing would be required because they fall below the 4 and 5 percent bands, as discussed below.

We prepared a range of burden estimates for this analysis and the discussion will mention minimum and maximum burden scenarios. These low and high estimates are intended to provide EPA's estimate of the outer boundaries of the likely testing and information costs, and EPA solicited comments on the basis of these estimates, including the number of additional tests, and the costs of performing such tests and of the additional tests that will be likely under the new regulations. EPA received no comments on the basis of these estimates, the number of additional tests, or the basic cost estimates for performing tests as presented in the proposal. Some comments were received on more specific costs issues, and these have resulted in some modifications to the cost estimate that will be noted below.

1. Test Volume

a. Testing Burden for MY 2008 through 2010

EPA estimates no additional tests during MY 2008 through MY 2010 based on the fact that the mpg-based fuel economy estimates will be available for all manufacturers. No additional testing would be required because manufacturers simply apply the mpg-based scale of adjustments to the same FTP and HFET test results that they otherwise would conduct for the fuel economy labeling program. While manufacturers have the option of conducting and reporting full five-cycle test results, such tests are not required. This cost analysis is limited to burdens that are mandated by the final rule.

b. Testing Burden for MY 2011 and After

The term “Test Volume” includes the labor and operations and maintenance (O&M) costs for running additional tests under the proposed requirements. Because of EPA’s facilities cost methodology, it also sets the capital cost estimates for ongoing facilities costs, as discussed below.

Based on MY 2004 data, 1250 fuel economy vehicles were tested with the FTP and highway fuel economy tests. (The figure is approximate because the city FTP test may be used and recorded primarily as a fuel economy test, an emissions test, or both.) Data show that 330 Supplemental FTP (US06 and SC03) tests were conducted and 220 Cold FTP tests. Consequently, if all fuel economy vehicles were required to conduct full five-cycle tests, approximately 920 additional Supplemental FTP tests and 1,030 Cold FTP tests would be required. Based on an analysis of our 615 vehicle dataset, we estimate that 8% of the test groups will fall outside a band of 〈≡~ 4% of the regression for the city test and 23% outside a band of 〈≡~ 5% of the highway regression. Taking the 2004 numbers above as a baseline, 92% of the additional SC03 and Cold FTP tests otherwise required would therefore be avoided for city fuel economy; 77% of the additional US06 tests would be avoided. Thus, for example, the initial estimate of increased testing burden for SC03 would be 8% of the difference between 1250 and 330.

This approach is retained in the final cost analysis, with one adjustment. The percent of vehicles triggering additional testing requirements because they fall outside the tolerance bands for the city and highway tests should only count those that are below the band in both cases; that is, only those with fuel economy lower than 4 and 5 percent below the regressions, respectively. With this correction applied to our updated 615-vehicle dataset, 4 percent of the test groups would trigger additional testing because they fall more than 4 percent below the city regression line, and 13 percent because they would fall more than 5 percent below the highway line. Thus, for example, the initial estimate of the increased testing burden for SC03 would be 4% of the difference between 1250 and 330, rather than 8%. The effect of this correction is that the baseline estimated ranges of additional tests in the proposal of 169-212 US06 tests, 59-74 SC03 tests, and 66-82 cold FTP tests, become 96-120, 29-37, and 33-41, respectively, for the final rule.

Finally, the high and low estimates under these assumptions are generated by differing estimates of the effect of another feature that will be available for MY 2011 and after: an expanded use of analytically derived fuel economy (ADFE) as an alternative to conducting vehicle tests. Current guidance (CCD-04-06) limits ADFE to 20% of the values that would otherwise be derived from tests; the 1250 test baseline already excludes such analytically derived results. Expanded ADFE guidance will be prepared in time for MY 2011 to allow for derivation of fuel economy values for some of the additional test cycles that otherwise would be required as described above. The low and high burden estimates assumes that 20% and 0% of the additional tests would thereby be avoided, respectively.

1) Fuel Economy Labeling for Medium-Duty Passenger Vehicles (MDPVs)

As discussed earlier, MDPVs will be included in the labeling program beginning with model year 2011. This change is congruent with NHTSA's expansion of the CAFE program to include MDPVs beginning the same model year. As discussed in Section II.D, we are finalizing fuel economy test methods for MDPVs that will not require additional testing beyond that which will already be required by the CAFE program beginning in model year 2011 (i.e., the FTP and HFET tests). Therefore, we are projecting no additional costs in this final rule to extend labeling to MDPVs.

2) Cold FTP Diesel Testing

The estimated cost impact of requiring cold FTP testing for light-duty diesel vehicles is small. As an example, in model year 2006, only five light-duty diesel vehicles were certified for sale in the U.S. A total of eight city/highway tests were performed on those vehicles to determine fuel economy estimates. Applied to the 2006 model year, our proposal would have required that an additional maximum of eight cold FTP tests be performed in addition to the city/highway tests. Our proposed cost analysis accounted for additional cold FTP testing across the entire automotive industry, including diesel vehicles.

While anticipating the makeup of the MY2011 diesel fleet is uncertain at this point, it seems prudent to anticipate some addition in the number of diesel vehicles certified and, as a result, we have assumed a doubling in the number of light duty diesels certified by MY 2011, and thus increased the number of light-duty diesel test groups to 10. This has increased the estimated Cold FTP test volume from 66 to 82 tests (proposed) and 33-41 tests as corrected above, to 41 to 49 tests (final). The consequent adjustment in testing costs is approximately $20,000 per year. This adjustment also has an effect on the estimated capital costs for testing facilities (see below for the methodology for estimating facility capital costs).

A separate capital cost addition for Cold FTP diesel testing facility upgrades is discussed below under Facility Burden.

The labor and O&M costs of conducting these estimated tests are derived from prior Information Collection Requests submitted for EPA's light duty certification program. Those estimates are based on the number of tests and the hours of labor used at EPA's testing facility combined with industry data supplied in response to questionnaires; these have been somewhat adjusted to reflect current information. These costs are estimated to range from $1,860 to $2,441 per test. These costs per test are applied to the numbers of tests estimated under the minimum and maximum scenarios above, and now amount to $343,000 to $424,000 and 5,000 to 6,200 hours per year for MY 2011 and after, compared to $$606,000 to $757,000 and 8,800 to 11,000 hours in the proposal.

This analysis is summarized in the tables below:

Table IV.A-1. Estimated Cost per Test: Proposed and Final

Test Cycle	Cost/Test	Hours/Test
FTP/HWY	$1,860	30
US06	$1,860	30
SC03	$2,206	30
Cold FTP	$2,441	30

Table IV.A-2. Estimated Increase in Number of Tests for Model Years 2008-2010: Proposed and Final

Test Cycle	2004 Model Year Number of Tests	Increase In Number of Tests: MY 2008 – 2010				Increase in Hours	
		Min Tests	Min $ Increase	Max Tests	Max $ Increase	Min	Max
FTP/HWY	1250						
US06	330	0	$0	0	$0	0	0
SC03	330	0	$0	0	$0	0	0
Cold FTP	220	0	$0	0	$0	0	0
		Min Increase =	$0	Max Increase =	$0	0	0

Table IV.A-3. Estimated Increase in Number of Tests for Model Years 2011 and Later: Proposed

Test Cycle	2004 Model Year Number of Tests	Increase In Number of Tests: MY 2010 And After				Increase in Hours	
		Min Tests	Min $ Increase	Max Tests	Max $ Increase	Min	Max
FTP/HWY	1250						
US06	330	169	$314,861	212	$393,576	5,078	6,348
SC03	330	59	$129,907	74	$162,384	1,766	2,208
Cold FTP	220	66	$160,904	82	$201,130	1,978	2,472
		Min Increase =	$605,672	Max Increase =	$757,090	8,822	11,028

Table IV.A-4. Estimated Increase in Number of Tests for Model Years 2011 and Later: Final

Test Cycle	2004 Model Year Number of Tests	Increase In Number of Tests: MY 2010 And After				Increase in Hours	
		Min Tests	Min $ Increase	Max Tests	Max $ Increase	Min	Max
FTP/HWY	1250						
US06	330	96	$177,965	120	$222,456	2,870	3,588
SC03	330	29	$ 64,954	37	$ 81,192	883	1,104
Cold FTP	220	41	$ 99,979	49	$120,092	1,229	1,476
		Min Increase =	$342,898	Max Increase =	$423,740	4,982	6,168

2. Facilities Burden

"Facilities" refers to the capital costs for constructing facilities to accommodate the increases in test volume estimated in the table above. For these capital costs we used an FTP facility cost of $4 million per facility able to perform 750 US06 tests per year, a cost of $9 million for an environmental test facility able to conduct 300 to 428 SC03 tests per year, and $10 million for an environmental facility able to conduct 300 to 428 Cold FTP tests per year. The new tests were deemed to require these facilities in proportion to the number of tests needed, and the costs were then annualized over ten years with a 7% discount rate. This is likely a very conservative assumption since it does not attempt to account for the excess capacity that exists in manufacturers' current test facilities. We assume that there is no excess capacity in our analysis. Furthermore, consistent with other information burden analyses for the emissions and fuel economy programs, we have considered these as ongoing capital rather than startup capital costs (i.e., as the facilities depreciate they are continually being replaced). Annualized and depreciated over ten years at 7%, these capital costs per year under the above analysis under the proposal were $0 for each of model years 2008, 2009 and 2010, and range from $524,000 to $866,000 per year for model years 2011 and after. Under the corrected and adjusted number of tests described the preceding section, the final annualized and discounted capital costs for model year 2011 and after range from $375,000 to $560,000.

In addition, commenters raised a number of technical issues regarding laboratory configurations and the difficulty of establishing cold test facility retrofits to accommodate diesel testing without a transition period. The 2011 effective date of the requirement is intended to address some of these concerns, particularly the lead time needed to implement laboratory adjustments, but we recognize that some facility updates will still be necessary. An additional capital cost of $55,000 for each of ten manufacturers has been added the proposed facilities costs to account for these adjustments in the final cost estimate. This figure includes the cost of flame ionization detectors (FIDs) as well as heated sample probes, sample lines and sample filters.

This cold facility upgrade for diesel testing, along with the corrected and adjusted projected number of tests, accounts for the changes in facility capital costs from the proposal.

This analysis is summarized in the tables below:

Table IV.A-5. Estimated Facility Costs: Proposed

	MY 2008 - 2010		MY 2011 And After	
Un-depreciated capital costs	Minimum	Maximum	Minimum	Maximum
FTP/HW	$0	$0	$0	$0
US06	$0	$0	$902,827	$1,128,533
SC03	$0	$0	$1,238,131	$2,208,000
Cold FTP	$0	$0	$1,540,187	$2,746,667
Total	$0	$0	$3,681,144	$6,083,200
Depreciated, 10yrs @ 7 %	$0	$0	$524,112	$866,111

Table IV.A-6. Estimated Facility Costs: Final

	MY 2008 - 2010		MY 2011 And After	
Un-depreciated capital costs	Minimum	Maximum	Minimum	Maximum
FTP/HW	$0	$0	$0	$0
US06	$0	$0	$510,293	$637,867
SC03	$0	$0	$619,065	$1,104,000
Cold FTP	$0	$0	$957,009	$1,640,000
Cold FTP facility upgrades	$0	$0	$550,000	$550,000
Total	$0	$0	$2,636,368	$3,931,867
Depreciated, 10yrs @ 7 %	$0	$0	$375,359	$559,809

3. Startup Burden

"Startup" refers to one-time costs beginning with model year 2008 to implement the new requirements in the final rule. These startup burdens are primarily information technology costs involving familiarization with the new data reporting requirements and reformatting management information systems to carry out and report the necessary data and calculations. With the exception noted below, all these burdens are add-ons to well established reporting requirements: manufacturers already submit data to EPA on all five test cycles, have the option of applying analytically derived fuel economy numbers, and report vehicle class determinations and supporting information. This part of the proposed estimate assumed four weeks for four information technology specialists for analysis and coding, and four weeks for two IT specialists for testing, at $100 per hour, for 35 manufacturers, based on a count of manufacturers in 2004 with an allowance for inter- and intra-corporate relationships. The estimate also includes 1,120 hours industry wide for label redesign. Startup information technology costs finally also include one-time costs and hours for implementing US06 split phase sampling, assuming one to seven days of programming. The remaining startup cost is the one-time costs associated with validation tests for the split phase sampling, and assumes one to seven tests at the costs per test given above. These one-time tests are not considered to entail ongoing capital costs but are treated as startup capital costs. EPA's proposal estimated all startup costs, discounted at 7% and annualized over ten years, as $526,000 to $615,000 and 3,815 to 4,718 hours.

a. Dual Information Systems Needed for CAFE/Gas Guzzler and Labeling

Currently, EPA's data system has a single “path” through which fuel economy data is passed. Up to the point of determining the so-called "model type" fuel economy, the calculations performed by the database are identical for both CAFE and labeling purposes. Then, the single path diverges: The label value is determined by applying the 10% and 22% downward adjustment factors to the city and highway model-type values, whereas, for CAFE, the model-type values are adjusted by a minor, but statutorily required, adjustment to account for test procedure differences since 1975.

The new rule would now require two separate data paths, since the new derived 5-cycle label calculations for labeling purposes would be carried through “from the bottom up” resulting in a model type fuel economy that needs no adjustment for "real world" conditions (i.e., model-type fuel economy for labeling purposes would be different from model-type fuel economy for CAFE purposes.). Consequently, it would no longer be possible to use the single existing calculation systems to determine the CAFE values.

EPA agrees that there may be some convenience in applying the derived 5-cycle equation at the model-type level for manufacturers who wish to use the same data management system for reporting CAFE and label values. This may be particularly true for the early part of the transition period. However, this approach is not available for the vehicle-specific 5-cycle label calculations, and any manufacturers who use it during the phase-in period during the 2008-2010 model years will encounter an information cost not contemplated in the proposal; a dual calculation procedure will be needed. Similarly, a dual calculating system will be needed for model years 2011 and after.

The cost analysis has been updated to account for this increased information system startup burden. Based on a projection of EPA’s information development contract costs, and an estimate of the portion of those costs attributable to the dual information system possibility, we have increased the industry information startup costs (unamortized) by $933,450. This increases the annualized and discounted startup costs to $659,000 to $748,000 for the industry as a whole, from the proposed level of $526,000 to $615,000.

The Final Technical Support Document has also been updated to delete labor hours attributed to startup costs. Startup costs are properly treated as capital costs, not labor.

The startup burdens are summarized in the following tables:

Table IV.A-7. Estimated Startup Costs: Proposed

Item	Cost		Hours	
	Minimum	Maximum	Minimum	Maximum
Information Tech/Paperwork				
Adjustment to new FE and label value computations and reporting of FE data for SFTP and Cold FTP and new ADFE calculations-- analysis, code development, and testing; label redesign	$3,472,000	$3,472,000	34,720	34,720
Sample system changes for US06 split phase	$28,000	$196,000	280	1,960
O&M				
Validation testing form US06 split phase sampling	$195,300	$651,000	3,150	10,500
TOTAL	$3,695,300	$4,319,000	38,150	47,180
Depreciate 10 years at 7%	$526,128	$614,928	3,815	4,718

Table IV.A-8. Estimated Startup Costs: Final

Item	Cost		Hours	
	Minimum	Maximum	Minimum	Maximum
Information Tech/Paperwork				
Adjustment to new FE and label value computations and reporting of FE data for SFTP and Cold FTP and new ADFE calculations-- analysis, code development, and testing; label redesign	$4,405,450	$4,405,450	0	0
Sample system changes for US06 split phase	$28,000	$196,000	0	0
O&M				
Validation testing form US06 split phase sampling	$195,300	$651,000	0	0
TOTAL	$4,628,750	$5,252,450	0	0
Depreciate 10 years at 7%	$659,002	$747,830	0	0

4. Summary

The combined results of the above tables can be summarized as follows: the final total estimated costs for each of Model Years 2008, 2009, and 2010 range from $659,000 to $748,000, and for Model Years 2011 and after, from $1,377,000 to $1,731,000. This is shown the tables below:

Table IV.A-9. Estimated Total Costs: Proposed

	MY 2008-2010			MY2011 and After	
	Min	Max		Min	Max
Test Volume	$0	$0		$605,672	$757,090
Facilities (annualized 10yrs/7%)	$0	$0		$524,112	$866,111
Startup: one-time IT/Paperwork and O&M (annualized 10yrs/7%)	$526,128	$614,928		$526,128	$614,928
Total	$526,128	$614,928		$1,655,912	$2,238,129

Table IV.A-10. Estimated Total Costs: Final

	MY 2008-2010			MY2011 and After	
	Min	Max		Min	Max
Test Volume	$0	$0		$342,898	$423,740
Facilities (annualized 10yrs/7%)	$0	$0		$375,359	$559,809
Startup: one-time IT and validation (annualized 10yrs/7%)	$659,002	$747,830		$659,002	$747,830
Total	$659,002	$747,830		$1,377,259	$1,731,380

The final combined burden hours shown in these tables is 4,982 to 6,168 hours for each model years beginning 2011 and continuing thereafter, as summarized below:

Table IV.A-11. Estimated Total Hours: Proposed

	MY 2008-2010			MY2011 and After	
	Min	Max		Min	Max
Test Volume (Labor, O&M)	0	0		8,822	11,028
Facilities (Capital, annualized 10yrs/7%)	0	0		0	0
Startup: one-time IT/Paperwork and O&M (Capital, annualized 10yrs/7%)	3,815	4,718		3,815	4,718
Total	3,815	4,718		12,637	15,746

Table IV.A-12. Estimated Total Hours: Final

	MY 2008-2010			MY2011 and After	
	Min	Max		Min	Max
Test Volume (Labor, O&M)	0	0		4,982	6,168
Facilities (Capital, annualized 10yrs/7%)	0	0		0	0
Startup: one-time IT/Paperwork and O&M (Capital, annualized 10yrs/7%)	0	0		0	0
Total	0	0		4,982	6,168

B. Impact on Confirmatory Testing of Vehicles

EPA can conduct confirmatory testing of any vehicle tested for emissions or fuel economy compliance purposes for any reason it deems necessary. EPA's fuel economy regulations currently specify certain conditions under which test results from manufacturers are to be confirmed, either by EPA at its own laboratory, or by the manufacturer. See 40 CFR 600.008-01. These conditions are tied to the FTP and highway test procedures, but do not address the US06, SC03 and Cold temperature FTP tests that will now included in fuel economy measurement. There are separate confirmatory test provisions in EPA's emission compliance regulations at 40 CFR 86.1835-01, which would continue to apply to all five test cycles.

Confirmatory testing is generally indicated for fuel economy purposes when the fuel economy falls near the cut point for Gas Guzzler Tax assessment, when the fuel economy (either city or highway) is unexpectedly high for that vehicle or falls near the leader within the comparable class. EPA provides guidance to manufacturers defining the actual criteria and cutpoints. Confirmatory testing is also required when the test results are close to or exceed the federal emission standard associated with the test. EPA also selects a random number of vehicles for confirmatory testing, and will request confirmatory testing on vehicles employing new or unusual technology.

In considering the impact of confirmatory testing of US06, SC03 and Cold temperature tests, some of the above criteria may or may not apply. For instance, the Gas Guzzler tax is based only on the FTP and Highway test procedures, so there would be no impact on confirmatory testing for the other procedures. However, if, in the course of performing a US06, SC03 or Cold temperature fuel economy test, an applicable emission standard should be exceeded, we believe that a confirmatory test would be necessary, per the current regulations.

Another reason to conduct additional tests is to resolve a disparity between confirmatory fuel economy test results. If a manufacturer's initial fuel economy test result does not compare closely to that of the confirmatory test, EPA requires a retest. (This requirement helps to establish correlation between manufacturer and EPA testing, providing assurance that manufacturer testing is properly conducted.) This currently applies only to FTP and Highway testing. If this requirement was applied equally to the US06, SC03 and Cold temperature FTP fuel economy tests, this could result in the need for additional tests. Obviously, EPA does not have established fuel economy correlation data for the US06, SC03 or Cold temperature FTP tests, because fuel economy has never been required to be measured. There is not enough fuel economy data to determine what constitutes reasonable correlation from one test to the next. Therefore, EPA does not plan at this time to conduct retests of US06, SC03 or cold temperature FTP tests on the basis of test-to-test fuel economy disparities. Once the final regulations for 5-cycle fuel economy are implemented, and more correlation data becomes available, we will assess whether or not we should establish retest criteria for US06, SC03 and cold temperature FTP tests on the basis of fuel economy test-to-test disparities.

C. Changes to Label Format and Content

Manufacturers are currently required to print and post fuel economy window stickers on all new cars and light trucks available for sale in the U.S. Our final rule does not change this requirement, thus no new costs for these activities will be incurred. The final changes to the format and content may require a one-time design change, but any additional costs are anticipated to be very slight, and mitigated by the design templates for the new labels which EPA is providing in the regulations. The reporting and recordkeeping requirements associated with the fuel economy label are set forth in 40 CFR sections 600.312 to 600.314. These sections require that manufacturers supply EPA with the label values and the data used to derive them, and provide schedules for the updating of this information. Under the final rule, these values will be recalculated and new data will be submitted. The costs for these efforts are very minimal and are addressed in the startup cost figures above. There will be a similar one-time set-up charge associated with the new label format based on the effort required for each manufacturer to apply the new EPA templates to the labels they must print. This cost item also has been included in the paperwork startup costs portion of the cost analysis.

D. Certification Fees

EPA collects fees from manufacturers to recover its costs associated with its emission and fuel economy compliance efforts. The fee amount is adjusted from time to time according to any changes to EPA's costs. The impact of the final rule changes is not anticipated to significantly increase EPA's efforts with the fuel economy labeling program; therefore, we are not proposing to adjust the fee amount at this time. However, we reserve the right to evaluate our actual incurred costs once the final rule is implemented and to propose fee changes if deemed appropriate.

Appendix A: EPA Kansas City Test Program

During 2004–2005, EPA in association with the Coordinating Research Council, STAPPA/ALAPCO, DOT and DOE/NREL,, recruited and tested over 600 privately owned passenger vehicles in the Kansas City area. The vehicles included an assortment of compact cars, mid-size cars, pick-ups and SUVs from a variety of manufacturers. The program was split into 3 rounds (1, 1.5 and 2), each consisting of 120-300 vehicles. In all three rounds, vehicles were recruited randomly from lists of vehicle registrations in the Kansas City area. Care was taken to ensure that the sample were random with respect to the geographic location of the owner and socio-economic status. In rounds 1 and 2, the desired sample of vehicles was stratified into four groups of model years, with emphasis on older vehicles[1,2]. The primary purpose of Rounds 1 and 2 was the quantification of particulate emissions, particularly those from high emitters. In Round 1.5, only 2001 and later model year vehicles were sampled. (Details about the design and performance of Round 1.5 are described the study's final report.[3]) The primary purpose of Round 1.5 was the measurement of onroad fuel economy from vehicles for which we could estimate 5-cycle fuel economy. This meant that we had to have fuel economy estimates over all five cycles for these vehicles (i.e., that the vehicle had to be certified to the Supplemental FTP standards). These standards began phasing in with the 2001 model year.

All of the vehicles In Rounds 1 and 2 were tested on a dynamometer, but only a subset of the vehicles were instrumented with a Portable Emissions Measurement System (PEMS) and tested in the hands of their owners. As these vehicles ranged in model year from 1968 to 2005, very few of the vehicles tested in Rounds 1 and 2 had been certified to the Supplemental FTP standards.

In Round 1.5, none of the vehicles were tested on a dynamometer. However, all of these vehicles were instrumented with PEMS and had their fuel economy measured while being driven in normal use by their owners. The round 1.5 vehicle fleet consisted of approximately 120 vehicles, including over 30 hybrid electric vehicles. The PEMS measures driving activity, as well as second-by-second mass emissions of CO_2, CO, HC, and NO_x for roughly 24 hours while the owners of the vehicles are utilizing their vehicles on the road under normal, real-world conditions. Two aspects of the PEMS limit the duration of its operation. One is the capacity of gas which is needed to operate the flame ionization detector used to measure HC emissions. The other is battery capacity needed to operate both the emissions measurement equipment and the onboard computer which scans vehicle activity and stores information. Using the carbon balance method, fuel economy can be accurately calculated on a second by second basis.

Since the focus of this proposed rule is fuel economy labeling, we are solely interested in the onroad fuel economy data collected during this program. We will not present, or discuss the results of the dynamometer testing, nor the emission test results. Because of this, we will focus primarily on Round 1.5, but will also include relevant data from Rounds 1 and 2, as appropriate. The reader is referred to this report for further information related to vehicle recruitment, selection, instrumentation, data processing and delivery.

The onroad fuel economy data will be used for several purposes:
1) To compare the onroad fuel economy for each vehicle to its fuel economy label values,

2) To compare the driving activity of vehicles in Kansas City to the findings of past studies, and 3) To develop 5-cycle formulae for each vehicle and compare the 5-cycle fuel economy to similar vehicles in our 5-cycle certification fuel economy database

Before moving to these three tasks, the following section will describe the methods we used to process and quality assure the data obtained from the PEMS.

A. Quality Assurance

Upon initial delivery of the data, we performed a number of tests on the data to identify equipment malfunctions. The removal of inaccurate data is referred herein as “flagging” (i.e., data are “flagged” when it meets a criterion designed to identify data which are not of acceptable quality). Flagging was performed using the SAS statistical package.

The initial step in quality assurance involved segregating vehicles into those with acceptable data and those with bad data. An entire set of bad data for a given vehicle was removed for a variety of reasons. Sometimes, the data collected for a given vehicle was completely missing vehicle speed or exhaust flow data, which are critical to proper processing of the data. In some cases, the vehicle was only driven for a few miles before the equipment stopped functioning. These data were insufficient to develop robust estimates of fuel use in the various VSP bins and to have confidence that the measured onroad fuel economy was indicative of that vehicle’s typical use. In one case, the CO2 emissions were outside a reasonable range. After this initial filtering of the data, there remained 9 vehicles from round 1, 97 vehicles from round 1.5 (including 33 hybrids), and 42 from round 2. These all constitute “good tests”. Data from 18 vehicles were removed in this step.

The next step in data processing involved removing or modifying individual seconds of data. We often found instances where the exhaust flow meter signal was zero, or erratic. There were several instances where the flow meter stopped functioning properly permanently (i.e., for the rest of the testing of that vehicle). This could have been due to freezing in the cold temperatures or simply from an electronic failure. For non-hybrids, if the vehicle was moving, but exhaust flow dropped to a value equivalent to engine off conditions, then the data was flagged and omitted from the final dataset. Unfortunately, this condition was impossible to flag systematically with hybrids, since the engine can shut off while the vehicle is on. Obvious cases of lengthy equipment failures during hybrid testing were flagged by hand. However, exhaust flowmeters were assumed to have been functioning properly during all hybrid runs.

Another frequent problem was that the signal from the vehicle’s onboard diagnostic (OBD) system, which provides measurements of vehicle speed, engine rpm, engine coolant temperature and other vehicle information, disappeared permanently or acted erratically. This is easy to spot since all of the OBD signals disappear at the same time. This can be caused by the driver accidentally knocking the connector, or it can be a result of manufacturer software settings. Fortunately, the PEMS units were equipped with a geographical positioning system (GPS) and vehicle speed could be calculated from the output from the GPS unit. These GPS estimates of vehicle speed were substituted for OBD speeds when the OBD speeds were absent or obviously erratic.

Sometimes the GPS speeds appeared to reflect anomalies (i.e., were clearly discontinuous, or drifted unrealistically over time). This was more of a concern regarding the calculation of vehicle acceleration than vehicle speed, due to the fact that required engine power is very dependent on small changes in acceleration. To identify unrealistically high accelerations, a cut-off was chosen at a specific power (the product of acceleration and speed, or v*a) of 300 mph^2/sec. Beyond this, the data were flagged (though these events were rare). Choosing a lower (and probably still realistic) maximum value would have resulted in excessive removal of data. . In addition, there were instances where the GPS speeds drifted slowly over time, usually when the car was not operating. These time segments were removed.

Table A-1 summarizes the processing of the data obtained with the PEMS.

Table A-1. Processing of Raw Data Obtained In Kansas City

	Round 1	Round 1.5	Round 2
Vehicles tested onroad with PEMS	18	117	52
Vehicles with some PEMS data	13	109	47
Vehicles with acceptable PEMS data	9	97	42
Total seconds of acceptable PEMS data while vehicle is in operation	53,319	501,405	181,915
Seconds of PEMS data removed	3,808	44,996	2,773

As can be seen, a total of 187 vehicles were equipped with PEMS units in Kansas City and the equipment worked to some degree on 169 of these vehicles (90%). Data from an additional 22 vehicles were rejected due to obvious equipment malfunctions, leaving 148 vehicles (78% of the original sample) with usable data. Of these 148 vehicles, 125 were conventional vehicles and 33 were hybrids. This usable activity and fuel economy data were obtained for a total of 736,000 seconds (over 200 hours) of driving from 148 vehicles, or roughly 80 minutes of driving per vehicle.

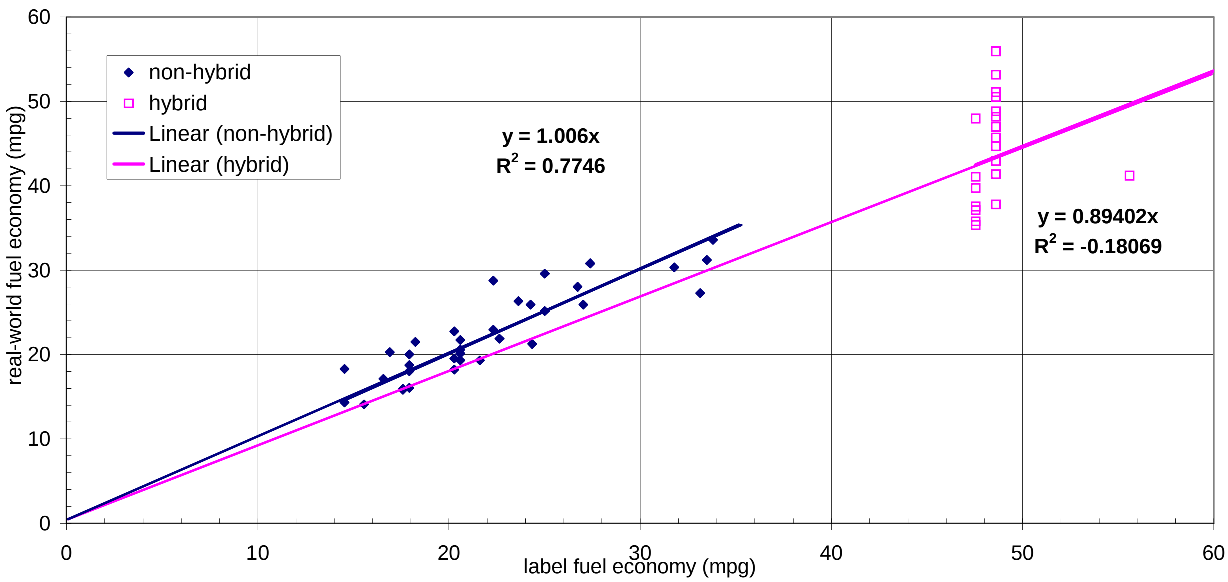
B. Onroad Fuel Economy

Total fuel consumption for each vehicle was determined from the carbon balance of the CO_2, HC, and CO emissions. The total distance of driving was determined by summing vehicle speed and multiplying by total time of operation. This total distance traveled was then divided by total fuel consumption to determine onroad fuel economy.

EPA city and highway label fuel economy values were obtained from EPA mileage guides. The test vehicles were matched to those tested in Kansas City to the closest degree possible. The following figure compares the measured fuel economy to the 55/45 composite label fuel economy from round 1.5 (newer vehicles). We segregated the vehicles into two groups: conventional gasoline-fueled vehicles and hybrids. A linear regression with no constant of the conventional vehicles showed nearly one-to-one correlation, with a slope of 1.006. The correlation was also quite good (r-squared value of 0.77). The largest difference was only 6 mpg, or about 30%. Thus, the onroad fuel economy data indicate no offset from the current EPA label values on average.

The correlation of hybrid data shows much more scatter. This is partially explained by the fact that only three hybrid models were tested, the Toyota Prius and the Honda Insight and Civic. On average, hybrid fuel economy was 11% less than the composite EPA label values. The average onroad fuel economy of the Toyota Prius vehicles was closer to their composite label values than those for the two Honda models. On average, the onroad fuel economy of the hybrids tested varied more than the conventional vehicles. This could be due to hybrids' greater sensitivity to operating conditions which can either take full advantage of the hybrid technology or essentially nullify it. The fact that most vehicles started out testing with a hot start likely biased onroad fuel economy upwards to some degree. Thus, the actual shortfalls found would have been greater to some degree if testing had begun with a cold start, which is more representative of a typical day of driving.

Figure A-1. Comparison Onroad to Current Label Economy: Kansas City



C. Recent Driving Activity in Kansas City and California

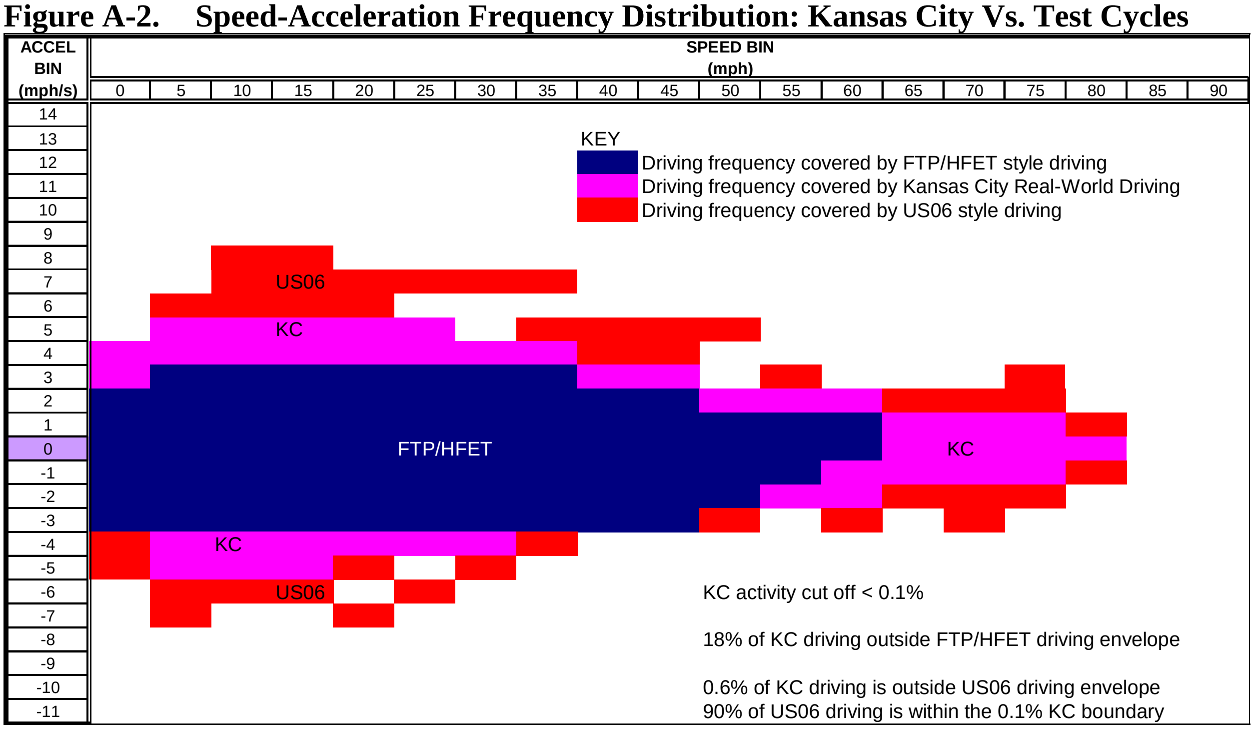
There are a number of ways to evaluate and compare driving activity. We evaluate two measures of driving here: 1) combinations of vehicle speed and acceleration and 2) VSP frequency distributions.

A common measure of driving activity is based on a speed acceleration frequency distribution or SAFD. This procedure divides individual seconds of driving into a 2 dimensional matrix of speed and acceleration. Here, we rounded accelerations to the nearest whole number and speeds to the nearest factor of 5 mph (i.e., 0, 5, 10, 15, etc.) If an acceleration was greater than 15 mph/sec, we set the acceleration to 15 mph/sec. If an acceleration was less than -15 mph/sec, we set the acceleration to -15 mph/sec.

There are two basic ways to display a SAFD. The more complex way is to show the percentage of driving for each combination (or bin) of speed and acceleration. The simpler way is to distinguish between those speed-acceleration bins for which onroad driving was found and those which did not. For ease of comparison with the SAFDs of dynamometer cycles, we use the simpler form of display here. We developed three SAFDs for the driving monitored in Kansas City: one for all vehicles, one for hybrids and one for conventional, or non-hybrid vehicles.

The SAFD for all of the vehicles tested with PEMS units in Kansas City is shown in the following figure. The breadth of onroad driving in Kansas City generally exceeds that of the FTP and HFET. Thus, for comparison, we show the SAFD for the FTP and HFET, as it represents an inner envelope of driving, *per se*. In some cases, the breadth of onroad driving in Kansas City generally exceeds that of the US06 cycle, as well. However, in some cases, it does not. Thus, in the figure, we indicate the driving in Kansas City which exceeds that of the FTP and HFET cycles. Then we show driving included in the US06 cycle which exceeds that found in Kansas City. In most cases, where the Kansas City driving forms the edge of the envelope, the US06 cycle also includes that type of driving. However, this is not true in all cases. Since the onroad data and the dynamometer cycles provide speed and acceleration rates for one second intervals and the HFET and US06 cycles are about 600 seconds long, the smallest amount of driving which can fall into a single bin in these two cases is 0.16%. Of course, smaller percentages of onroad driving can fall into a single bin due to the large number of observations available. To be comparable with the driving cycles, we only considered onroad driving to adequately populate a specific speed-acceleration combination if at least 0.1% of all onroad driving fell into that bin.

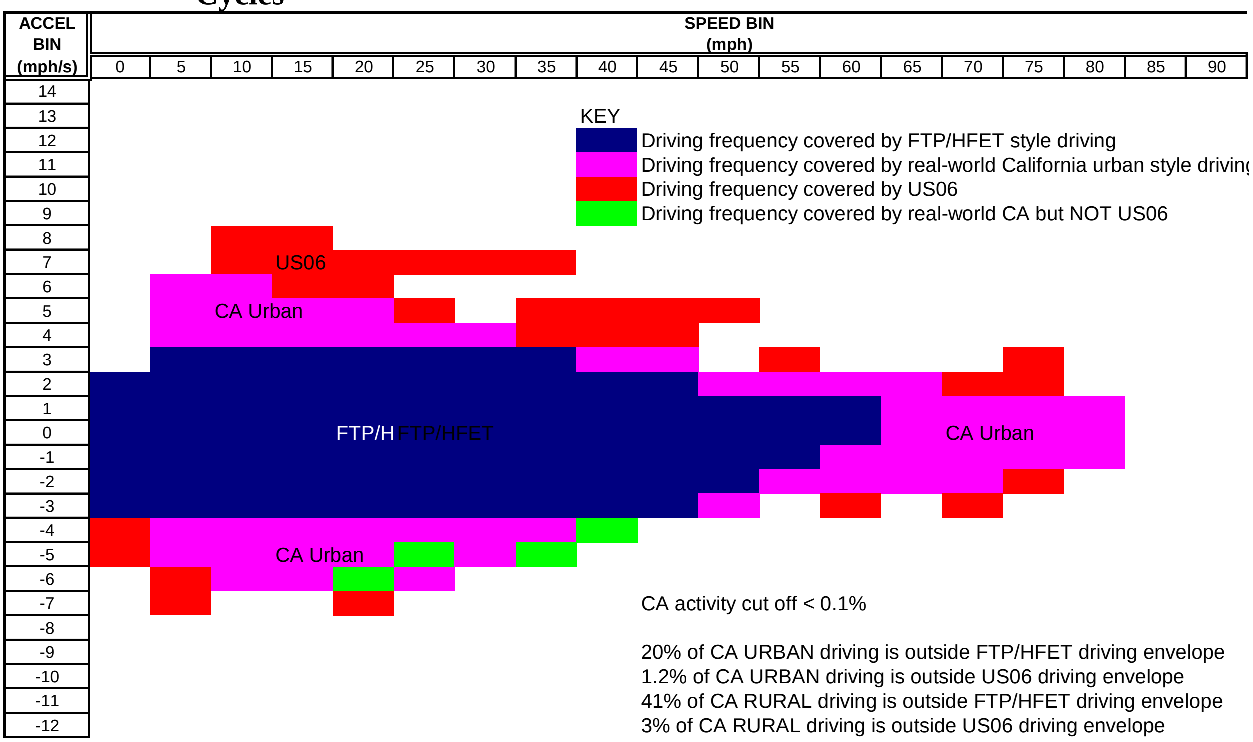
Figure A-2. Speed-Acceleration Frequency Distribution: Kansas City Vs. Test Cycles



Overall, 18% of the onroad driving activity (time based) in Kansas City fell outside of the FTP/HFET envelope. This corresponds to 33% in VMT terms. However, only 0.6% fell outside the US06 (0.4% of the VMT). These are data in the white cells, which are populated but fall below 0.1% of the total. Overall, 25% of the driving activity in Kansas City fell outside the FTP envelope alone (40% of the VMT). Comparing to most speed limits, 28% of the VMT was compiled greater than 65 mph. The SAFD envelopes for hybrid and conventional vehicles did not differ significantly from each other. However, the percentages of driving in the various bins did vary, as will become more evident below when we evaluate the VSP frequency distributions for the two types of vehicles.

We also show the SAFD driving activity found from a chase car study conducted in Los Angeles in 2000 in this figure[4]. This study observed roughly 390 hours of vehicle operation. According to the data, 20% of California urban driving lies outside the FTP/HFET envelope (34% of the VMT). 1.2% fell outside the US06 envelope (1.3% of the VMT). 25% of the driving occurred outside of the FTP alone (42% of the VMT). However note that much more of the rural driving was outside the US06 envelope (3%).

Figure A-3. Speed-Acceleration Frequency Distribution: Urban California Vs. Test Cycles



Moving to VSP, we calculated the level of VSP for each second of each vehicle's driving from the vehicle's speed and acceleration, plus its road load characteristics and vehicle mass. The equation used is shown below:

$$VSP = (Av + Bv^2 + Cv^3 + Mva)/M,$$

where v is vehicle speed, a is acceleration, A, B, and C are the road load (coast-down) coefficients of the vehicles and M is the mass of the vehicle.

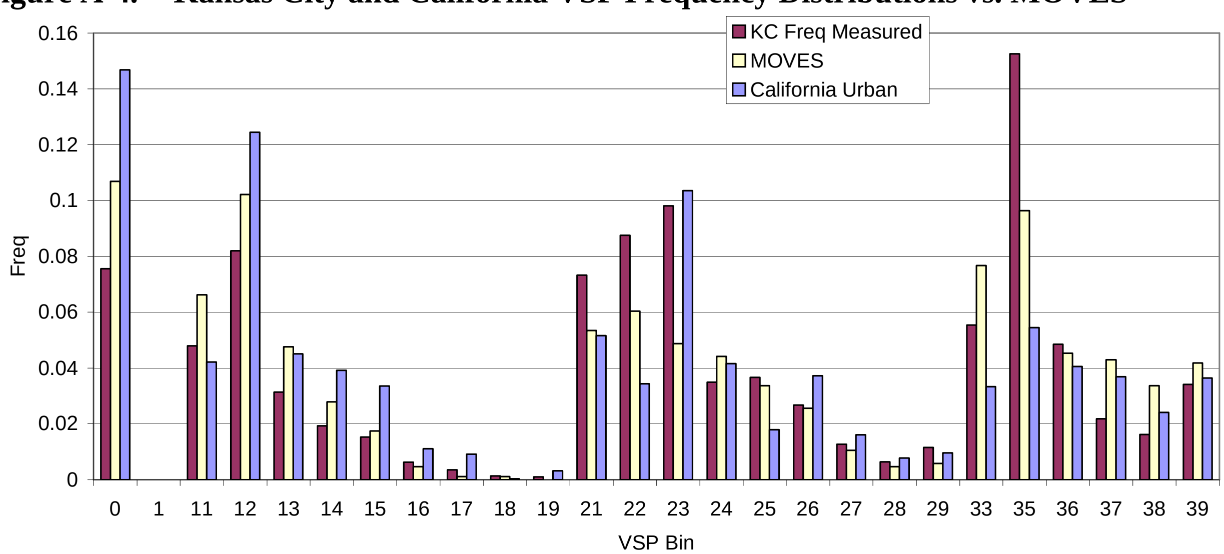
This is the same method used in section IA.2 to convert the facility driving cycles in MOVES into VSP frequency distributions. The only difference is that here, the constants A, B, C and M are specific to the vehicle being monitored on the road. For the MOVES cycles, we used coefficients indicative of the average car and light truck on the road.

Road grade can also be included in the above equation. We did not include this term, because the altitude data from the GPS unit appeared quite unreliable. Therefore, the effect of road grade is not reflected in our analysis and remains a source of uncertainty in the results. We obtained the specific vehicle parameters from EPA's Inspection and Maintenance database based on the model year, make and model of the vehicle. The vehicles were not weighed on a scale, so the actual weights may vary somewhat from those in the database.

The Kansas City driving activity was binned by VSP and vehicle speed as described in section IA.2. We used 26 VSP bins, which includes the addition of 9 high power bins beyond those used currently in Draft MOVES2004. Bin 0 contains significant decelerations, while Bin 1 contains idle operation. Bins 11-19 include other operation below 25 mph. Bins 21-29 include operation between 25 and 50 mph and Bins 33-39 include operation above 50 mph. Bins x1 contain operation with very low or negative engine power, while Bins x9 contain very high power operation.

The following figure compares the Kansas City activity in terms of VSP bin to that used in Draft MOVES2004 and described in section IA.2 (Table IA-12). The match in trends is reasonable, though Draft MOVES2004 projects roughly 4% more activity in the high speed, high power Bins 36-39 and 4% less activity in the lower power Bin 35.

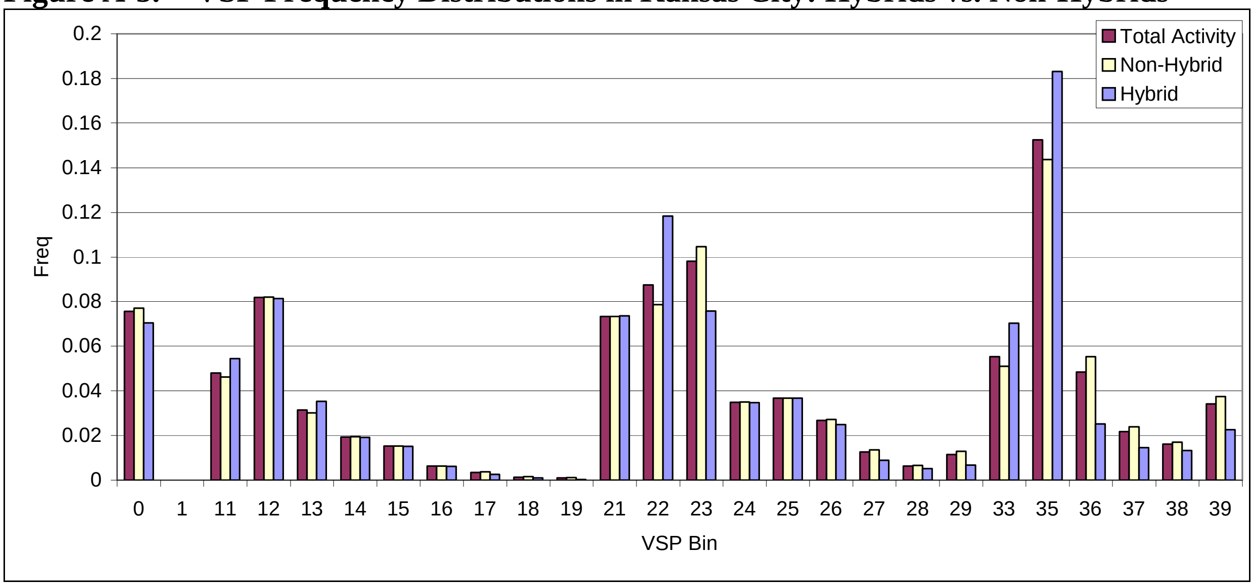
Figure A-4. Kansas City and California VSP Frequency Distributions vs. MOVES



We also show the driving activity found from a chase car study conducted in Los Angeles in 2000 in this figure[5]. This study observed roughly 390 hours of vehicle operation. This VSP frequency distribution was estimated from the speed acceleration frequency distributions developed from the chase car data[6]. The portion of driving found the Bins 36-39 in Los Angeles matches that in MOVES2004, though there is about 1% less operation in Bins 26-29. One must be cautious when comparing activity data from instrumented vehicles and chase cars. Chase cars do not follow drivers throughout their entire trip, so operation on local neighbor roads is often missed. Also, the VSP distribution from Draft MOVES2004 includes both urban and rural operation, while those of Kansas City and Los Angeles are primarily urban. This could introduce some differences, as well.

The following figure shows the VSP frequency distributions for the three groups of Kansas City vehicles mentioned above: all vehicles, hybrids and non-hybrids. We removed idle (bin 0) prior to calculating the VSP distributions for two reasons. One, idle percentages were extremely high and if depicted in the figure, would have made the rest of the bars difficult to read. Second, given that little fuel is consumed during idle, including the percentage of time at idle distorts the comparison of those VSP bins where fuel consumption is more significant.

Figure A-5. VSP Frequency Distributions in Kansas City: Hybrids vs. Non-Hybrids



As can be seen from a close look at the operation in the higher power bins (x6-x9), the driving of hybrids tends to be less aggressive than that of conventional vehicles. The percentage of time spent driving in bins 26-29 and 36-39 is 5-6% lower for hybrids than conventional vehicles. This is of interest, as this study is likely to be the first to examine the relative operation of conventional and hybrid vehicles. If there was something about hybrid vehicles which always led them to be operated less aggressively, this might need to be considered in developing their fuel economy label value.

There are several possible explanations for this difference. One cause could be a limitation in the power of the hybrids monitored in Kansas City. All but one of the hybrids were either a Prius or a Civic, which were clearly designed for fuel efficiency with some sacrifice in power. Another cause could be driver behavior. People purchasing hybrids may have an unusually high interest in achieving high fuel economy on the road and drive their vehicles less aggressively, knowing that aggressive driving reduces fuel economy. This could either represent a change in driving behavior towards less aggressiveness with the purchase of a hybrid, or these drivers may have driven their previous vehicle the same way.

Of particular interest is whether the difference in the operation of conventional vehicles and hybrids will continue in the future or disappear. If the difference is due to a low power vehicle design, then the difference depends on the design of future hybrids. Most of the recently introduced hybrids match (or even exceed) the power output of their non-hybrid counterparts. Thus, this difference in vehicle operation found in Kansas City may soon disappear.

If the drivers of hybrids in Kansas City always drove in the manner captured in this study, then this implies that people conscious of fuel efficiency tend to be the first people to buy hybrids. In this case, the difference in operation would continue until hybrids become the dominant drivetrain. As more and more people purchase hybrids, the driving of hybrids would likely become more aggressive, since the new hybrid purchasers are coming from the remaining, more aggressive pool of drivers. The driving of conventional vehicles would also become more aggressive as the less aggressive drivers of conventional vehicles buy hybrids. Overall driving operation would likely remain the same, but the driving of the two pools would shift over time, tending to remain distinct from each other.

Finally, the drivers of hybrids in Kansas City may have changed their driving behavior when they purchased their hybrids. Some manufacturers of hybrids offer training classes or videos to help hybrid owners get the most from their hybrid technology. If this trend continued, hybrid driving activity would tend to always be less aggressive than that of conventional vehicles. As more hybrids enter the fleet, the overall driving of the fleet would become less aggressive. Even if the drivers of current hybrids have changed their driving behavior, the question exists whether this trend would continue as hybrids become more popular.

This is the first systematic study of the onroad operation of hybrids in the hands of typical owners. Only about 45 hours of operation were studied. Thus, there is significant uncertainty in the difference found in the operation of conventional and hybrid vehicles. As discussed in section I.A, we are in the process of obtaining a large volume of operational (activity) data obtained in Atlanta. Some hybrid vehicles may be included in this database. We plan to compare the operation of conventional and hybrid vehicles in that study as soon as we receive the data. Still, the potential impact of the difference in driving behavior for the two types of vehicles is examined in section III.E.4.

D. Evaluation of 5-Cycle Approach to Fuel Economy Estimation

In section I.A.2.b, we developed combinations of dynamometer cycles which best represented the driving activity represented in Draft MOVES2004. In an earlier publication, we also developed a methodology by which real-world driving could be fit by 3 cycles (FTP, HFET, and US06).[7] We repeated this analysis using the VSP frequency distributions shown in Figure

II-5 above and additional cycle combinations. This analysis and its results are described in detail in section III.E.4. Because the Kansas City study measured the driving activity of each vehicle separately, as well as its second by second fuel consumption, we can develop dynamometer cycle combinations which best represent the driving of each vehicle. These cycle combinations can then be used in the 5-cycle formula to predict onroad fuel economy. These vehicle specific 5-cycle fuel economies can then be compared to the measured onroad fuel economy to assess the accuracy of the 5-cycle methodology.

One caveat regarding this comparison is that we need estimates of fuel economy over the five dynamometer cycles to use in the 5-cycle formula. These generally only exist for vehicles certified to the Supplemental FTP standards, which began phasing in with the 2001 model year. Very few of the vehicles tested with a PEMS unit on the road in Rounds 1 and 2 of the Kansas City test program were from the 2001 and later model years. Therefore, we only performed this analysis for vehicles from Round 1.5. Even with this restriction, we still do not have fuel economy measurements over the 5 dynamometer cycles for many of the vehicles tested in Round 1.5.

The first step in the analysis was to develop a VSP frequency distribution for each vehicle's onroad driving. The same methods were used to do this as were used above in developing the VSP frequency distributions for all the Kansas City vehicles. The only difference is that it was done for each vehicle individually.

The second step was to develop VSP frequency distributions for the five dynamometer bags and cycles for each vehicle. These distributions are very similar to those shown in Table IA-15. The only difference is that we used vehicle-specific values for the constants A, B, C and M instead of the fleet-average estimates contained in Draft MOVES2004.

The third step was to calculate an average rate of fuel consumption for each vehicle's operation in each VSP bin.   This was done by calculating the rate of fuel consumption for each second of vehicle operation using the carbon balance method. For each vehicle, the seconds of operation were grouped by VSP bin and the fuel rates for these times of operation averaged. If no onroad operation occurred in a particular bin for a particular vehicle, the fuel consumption in that bin was set to the rate of fuel consumption in the nearest bin having the same level of power (e.g., bin 38 average fuel consumption is set to that found for bin 28). If no operation occurred in any of the other bins of the same power level, the rate of fuel consumption was set to the average rate of fuel consumption for other similar vehicles in that bin. Here, similar means either conventional or hybrid. In other words, if no operation occurred in bin 18, 28, or 28, then the rate of fuel consumption in each of these bins for a conventional vehicle was set to the rate of fuel consumption in each of these bins for all the conventional vehicles which operated in each bin. The same approach was taken for hybrid vehicles.

We restricted the calculation of fuel rates to warmed up driving (i.e., after the effects of the cold start had ceased). We first had to determine when an engine start occurred. Along with this we determined how long the engine had been turned off (i.e., the soak time).

We used two criteria for determining the point in each trip when the engine was fully warmed up. The first applied to those vehicles without coolant temperature data. The second applied to those vehicles with coolant temperature data. Engine coolant temperature data was only available for some of the vehicles, so the latter criterion could be not extended to all of the Kansas City vehicles

For vehicles without coolant temperature data, we assumed that the engine was fully warmed up after the engine had been running for 200 seconds. For those with such data, we first smoothed out fluctuations in the coolant temperature data by calculating a five-second average temperature for a time t which is the average of the coolant temperature at that time, the two seconds prior to time t and the two seconds subsequent to time t. For all operation beyond the 200^{th} second after a start, we calculated the mean and standard deviation of what we considered to be the warmed-up coolant temperature. The first second when the five-second average temperature fell within 1 standard deviation of the mean coolant temperature was estimated to be the time at which the engine was first fully warmed up.

As described in section I.A.2, we regressed the VSP distributions for the 5 dynamometer cycles and bags against that of the onroad driving for each vehicle. We weighted the square of the error by the rate of fuel consumption in each bin, then minimized the weighted error. Unlike the analyses described in section I.A.2, here we used SAS to perform the analyses due to the large number of vehicles involved. In all cases, the sum of the dynamometer cycle coefficients was set to equal 1.0 and the intercept was set to zero.

We developed two sets of dynamometer cycle combinations for each vehicle. One used the five dynamometer cycles and bags used in section I.A.2, namely: Bags 2 and 3 of the FTP, HFET, US06 city and US06 highway. A second set of regressions was performed using only three of these cycles and bags, namely Bags 2 and 3 of the FTP and HFET. This second set of regressions represents what is called here the “3-cycle” methodology. It represents a way of estimating onroad fuel economy using only the current two fuel economy tests, the FTP and HFET. It does not include the US06 cycle, either in whole or in part. No attempt was made to segregate a vehicle’s driving into city or highway modes. Thus, each regression represents all of the driving by an individual vehicle and the predicted fuel economy is then comparable to the overall fuel economy of that vehicle on the road during the duration of the PEMS testing.

The initial weighted regression for each vehicle sometimes produced cycle coefficients which were negative. Those cycles with negative coefficients were removed, one-by-one, starting with the cycle with the coefficient of the largest magnitude. Once all regression coefficients were non-negative, the regression procedure was stopped and the results accepted. No attempt was made to further remove cycles with positive coefficients which might not pass a statistical significance test of some sort.

For example, vehicle number 521, a 2003 Mitsubishi Montero Sport, was driven 46 miles while its fuel economy and activity were being monitored. The cycle representation of its driving is shown in Table A-2.

Table A-2. Cycle Combinations for the Mitsubishi Montero Sport

	Bag 3	Bag 2	HFET	US06 Highway	US06 City
Time Basis					
3-cycle combination	68.6%	0%	31.4%	----	----
5-cycle combination	66.0%	0.2%	0%	33.7%	0%
Mileage Basis					
3-cycle combination	53.7%	0%	46.3%	----	----
5-cycle combination	45.0%	0.1%	0%	54.9%	0%
Fuel Economy	16.7	19.9	23.4	19.4	11.4

The regression of VSP, weighted by fuel consumption, provides cycle combinations in terms of the percentage of time spent driving in each cycle. As was described in section I.A.2, these percentages of time are converted to percentages of miles traveled using the average speed of each dynamometer cycle and bag.

As can be seen in Table A-2, without consideration of US06, about two-thirds of the Montero's driving time is represented by Bag 3 and one-third by HFET. When we include US06 in the calculation, the Bag 3 contribution changes very little. The driving previously represented by HFET shifts entirely to US06 highway.

In order to use the cycle combinations to predict onroad fuel economy, we need estimates of each vehicle's fuel economy over the five cycles. The vehicles tested in Kansas City were not tested over the dynamometer cycles. We estimated the fuel economy for each bag or cycle for each Kansas City vehicle from the test results of similar vehicles in our 5-cycle fuel economy database of 615 vehicles. The fuel economy estimates for the Montero are shown in the last row of Table A-2. Warmed up onroad fuel economy can be estimated by simply summing the product of the fuel economy of each bag and cycle and that bag's or cycle's contribution to 3-cycle or 5-cycle driving.

We were able to match up 71 of the vehicles tested in Round 1.5 to those in our 5-cycle fuel economy database. Of these vehicles, 53 were conventional vehicles and 18 were hybrids.[j] Generally, differences exist between the Kansas City and certification vehicles, as the latter are selected based on their worse case nature regarding emissions and the former are likely to be high sales volume vehicles. This could cause the 3-cycle and 5-cycle estimates of fuel economy to somewhat low. We present an analysis at the end of this section which sheds some light on this issue.

In order to further refine the 3-cycle and 5-cycle estimates, we then included fuel use related to engine starts. This basically involved determining how many times the engine was started while the vehicle's operation was being monitored, the soak time prior to each engine start and the ambient temperature at the time of each start. If a trip lasted less than 10 seconds, we assumed that it did not occur. The time associated with this trip was made part of the soak

[j] Nearly half of the hybrids tested were pre-2004 model year Prius vehicles. We do not have 5-cycle fuel economy values for this model.

time prior to the next trip. We also deleted trips when more than 5% of the trip's data were discarded for reasons described above.

The ambient temperature at the time of the engine start was estimated from the time and day of the engine start and local meteorology data from the National Weather Service. We estimated the total fuel related to engine starts using the same methodology applied to the Draft MOVES2004 estimates of annual engine starts throughout the nation and described in section I.A.1. Each engine start had a previous soak time and ambient temperature associated with it. The start fuel use related to this engine start was estimated in terms of the start fuel use related to a cold start at 75°F using the equations for the effect of start fuel use as a function of soak time and ambient temperature presented in section I.A.1. The 75°F cold start equivalents for each start were summed across all of the starts for each vehicle to estimate the total number of 75°F cold start equivalents for each vehicle's monitored driving. We did not have a measured soak time prior to the first start of monitored operation, as the equipment was by necessity installed while the engine was turned off. We assumed that amount of time that the equipment was operating prior to the first engine start was the soak time prior to that start. This tended to be only a matter of minutes. Practically, this was equivalent to assuming that the first engine start was a hot start, though in some rare cases the vehicle had sat overnight since its last operation. Thus, this is one certain source of uncertainty in the estimation procedure. We estimated the sensitivity of the estimated onroad fuel economy due to this uncertainty by evaluating the impact of adding one cold start to the number of equivalent cold starts.

For example, the Montero took three trips while being monitored. The first was preceded by a soak of 12 minutes, the second by 99 minutes and the third by 3 minutes. The ambient temperature for all the starts ranged only from 24-25 F. Using the equations presented in section I.A.1, the total number of cold starts ignoring the effect of ambient temperature was 0.47 for the three starts. The total number of 75°F cold start equivalents including the effect of ambient temperature was 0.96 for the three starts. The latter estimate assumes that the cold start fuel use (the difference in fuel consumption in Bags 1 and 3 multiplied by 3.59 miles) at 20°F is 2.75 times that at 75°F. We determined this ratio for each vehicle using the actual or estimated fuel economy values for Bags 1 and 3 at 20°F and 75°F from our 5-cycle fuel economy database. The ratio for the Montero was 2.16, meaning that the cold start fuel use only increased by a factor of 2.16 between 75°F and 20F, or 22% less than that assumed in Draft MOVES2004 for the typical vehicle. Thus, we multiplied the equivalent number of cold starts at 75°F (0.96) by the ratio of 2.16 to 2.75 to make the estimate of the equivalent number of cold starts at 75°F specific to the cold start fuel use of the Montero. This reduced the estimate of the equivalent number of cold starts at 75°F for the Montero to 0.75.

We then multiplied the cold start fuel use at 75°F for the Montero by the number of cold start equivalents. For the 3-cycle estimate of onroad fuel economy, we used a value of 0.47 for the number of cold start equivalents, since the FTP and HFET only provide fuel economy information at 75°F. For the 5-cycle estimate of onroad fuel economy, we used a value of 0.75 for the number of cold start equivalents, since the availability of the cold FTP provides the additional fuel economy information at 20°F.

Finally, for the 5-cycle estimate of onroad fuel economy, we included an estimate of the effect of temperature on running fuel use. We estimated the ambient temperature at the time of the start of each trip and then weighted these temperatures by the length of each trip in order to estimate an average temperature while the vehicle was operating. For the Montero, this was 24.7 F. We then calculated a percentage indicating the degree to which this temperature represented the temperature drop from 75°F to 20°F; in this case, 91%. Consistent with the 5-cycle formulae, for the percentage of driven mileage represented by HFET and US06 highway, we increased running fuel use by 4% multiplied by the percentage of the temperature drop from 75°F to 20°F. For the percentage of driven mileage represented by Bags 2 and 3 and US06 city, we calculated running fuel use as the sum of :

1) 100% minus the temperature percentage (9%) times the running fuel use at 75°F (a function of fuel economy over Bags 2 and 3 and US06 City), plus

2) the temperature percentage (91%) times the running fuel use at 20°F (a function of fuel economy over Bags 2 and 3, with half of the mileage weight of US06 City added to each Bag).

We were able to match 71 vehicles from those successfully tested in Kansas City to vehicles in our 5-cycle fuel economy database. Using the procedures just described, we estimated 3-cycle and 5-cycle fuel economies for each vehicle and averaged the results across all 91 vehicles. The results are shown in Table A-3.

Table A-3. Onroad and Predicted Fuel Economy: Kansas City Test Program

	3-Cycle Predicted		5-Cycle Predicted	
	Fuel Economy (mpg)	Coefficient of Variation of Error	Fuel Economy (mpg)	Coefficient of Variation of Error
Onroad fuel economy	28.3	----	28.3	----
Predicted Fuel Economy				
Warmed up fuel economy	32.2	18%	29.9	17%
With cold starts at 75°F	32.0	18%	29.7	17%
With cold starts at ambient temp.	----	----	29.2	17%
With running fuel use at ambient temp	----	----	27.7	17%

As indicated in Table A-3, the average onroad fuel economy of the 71 vehicles (each vehicle weighted equally, not by mileage of travel) was 28.3 mpg. Using only the cycle combinations to predict onroad fuel economy over-predicted onroad fuel economy using both three cycles and five cycles, as would be expected. The overprediction is smaller for five cycles than three cycles (1.6 mpg versus 3.9 mpg), indicating the benefit of including the US06 city and highway bags in predicting onroad fuel economy. Also shown in Table A-5 are the coefficients of variation of the percentage differences in the predicted versus onroad fuel economy for each of the 71 vehicles. This metric provides an indication of the consistency of the prediction. A low coefficient of variation, even if there is a large, but consistent offset, would indicate that a significant factor was missing from the prediction, like cold start fuel use, but to a consistent degree across all of the vehicles.

Adding cold start fuel use as if all starts were at 75°F (as assumed in the FTP) reduces the difference between predicted and onroad fuel economy in both cases by the same 0.2 mpg. The coefficients of variation remain unchanged.

Adding cold start fuel use at the estimated ambient temperature is only applicable to the 5-cycle prediction. This factor reduces the difference between predicted and onroad fuel economy by 0.5 mpg. The coefficient of variation, however, does not change. One would have expected it to decrease at least slightly, since the ambient temperatures at which the vehicles were started varied. Three possible reasons for this outcome exist. One, the effect of these temperature differences was so small that total fuel use varied very little even for specific vehicles. Two, the data for soak times were inaccurate, particularly due to the unknown soak prior to the first start. Or, three, the difference in Bag 1 and Bag 3 fuel economy at 20°F is not a good predictor of excess fuel use at temperatures which tended to fall in the range of 20 and 75°F. In terms of predicting onroad fuel economy, though, considering the ambient temperature of engine starts reduces the difference between the 5-cycle fuel economy estimate and onroad fuel economy by 2%.

Adding the effect of ambient temperature on running fuel use had a larger effect on predicted fuel economy than the effect of cold starts at 75°F or ambient temperature. This reduced the predicted 5-cycle from 0.9 mpg above onroad fuel economy to 0.5 mpg below it, for a final difference of less than 2%.

The difference between the 3-cycle and 5-cycle formulae is even more dramatic for non-hybrid vehicles. The difference between the best 3-cycle prediction and the onroad measurement for hybrids averages 24%, while that for the best 5-cycle prediction is only 3%.

The VSP based approach to predicting onroad fuel economy was equally successful when applied in a 15 car study conducted by EPA in 2001. Table A-4 presents the measured onroad fuel economy of the 15 cars and fuel economy predictions using two different approaches. One approach used the VSP methodology developed for Draft MOVES2004 (see section I.A.2) to determine the mix of FTP, HFET and US06 driving which best matched each vehicle's onroad driving pattern. This approach under-estimated onroad fuel economy by 4%. The other approach used average onroad speed to determine the mix of FTP and HFET driving which best matched each vehicle's onroad driving pattern. This approach over-estimated onroad fuel economy by 24%. One advantage of the 15-car test program was that most of the 15 cars were tested over the FTP and US06 as part of the study. Therefore, the dynamometer fuel economy values used in the predictions were those for the specific vehicles tested onroad. In the Kansas City program, we had to match the vehicles tested onroad to those in our 5-cycle certification database. These matches may have been closer in some cases than others, causing the 5-cycle fuel economy to slightly under-predict onroad fuel economy on average in Kansas City.

Table A-4. On-road and Modeled Fuel Economies Using Vehicle-Specific Cycle Weights (mpg)

Veh. No.	Fuel Economy (mpg)			% Difference	
	On-road	Modeled			
		VSP (FTP, HFET, US06)	Speed (FTP, HFET)	VSP (FTP, HFET, US06)	Speed (FTP, HFET)
1	24.8	26.3	27.4	6.3%	10.4%
2	26.2	23.2	34.0	-11.4%	30.0%
3	27.2	28.7	31.5	5.5%	15.8%
4	19.5	N/A	30.5	N/A	56.6%
5	32.0	N/A	32.5	N/A	1.7%
6	24.7	25.1	28.5	1.6%	15.3%
7	40.9	N/A	40.0	N/A	-2.4%
8	29.5	28.5	38.0	-3.3%	29.0%
11	26.0	23.8	34.6	-8.6%	33.1%
12	27.9	25.4	40.7	-8.9%	46.0%
13	22.5	22.8	30.7	1.0%	36.1%
14	15.6	14.5	19.9	-7.1%	27.4%
15	26.8	N/A	30.9	N/A	15.2%
17	26.5	N/A	26.7	N/A	0.5%
18	17.8	15.5	18.3	-12.8%	2.5%
Average (10 vehicles w/ VSP based estimates)				-3.8%	24.6%
Standard Deviation (10 vehicles)				7.0%	13.2%

Finally, in an effort to better understand the cause of the difference between predicted and onroad fuel economy reflected in Table A-4, we reversed this analysis. Instead of using fuel economy measured over dynamometer cycles to predict onroad fuel economy, we used the onroad fuel measurements to predict cycle fuel economy. We did this using the VSP methodology. Each combination of vehicle and dynamometer cycle has its own VSP frequency distribution. We simply weighted the measured onroad fuel consumption in each VSP bin for each vehicle by this cycle-specific VSP frequency distribution to estimate the average rate of fuel use (in gallons per second) over that cycle. We then converted this fuel rate to fuel economy using the average speed of each dynamometer cycle. Table A-5 shows the measured and predicted fuel economy values for four dynamometer bags or cycles. When comparing the predicted fuel economy over the dynamometer cycles to measured values, we found significant differences between hybrids and conventional vehicles. Thus, Table A-5 presents the results of this analysis separately for conventional vehicles and hybrids.

Table A-5. Comparison of Cycle Fuel Economy

	Bag 2	Bag 3	HFET	US06
Conventional Vehicles				
Predicted from onroad fuel rates (mpg)	16.5	20.7	28.6	24.3
Measured in lab @ 75°F (mpg)	21.5	25.0	34.0	22.5
% Difference	30%	21%	**19%**	**-7%**
Measured in lab: adjusted for temperature (mpg)	20.5	24.0	---	---
% Difference	**26%**	**16%**	---	---
Hybrids				
Predicted from onroad fuel rates (mpg)	32.4	38.4	51.5	43.3
Measured in lab @ 75°F (mpg)	61.8	53.9	61.8	41.6
% Difference	91%	40%	**20%**	**-4%**
Measured in lab: adjusted for temperature (mpg)	47.6	46.9	---	---
% Difference	**46%**	**22%**	---	---

For conventional vehicles, cycle/bag fuel economy from the 5-cycle certification database are higher than those predicted from second-by-second onroad fuel rates for Bags 2 and 3 of the FTP and HFET. The differences are fairly significant, ranging from 19-30%. However, the situation reverses for US06, with the measured cycle fuel economy being 7% lower than that predicted from the onroad fuel measurements. These differences can be due to differences in vehicle operation on the road and on the dynamometer and to differences between the physical vehicles tested in both cases. As mentioned above, the vehicles which are generally included in our 5-cycle certification database represent the worse case vehicle configuration within their broader vehicle groupings. Worse case might include four wheel drive, higher inertia weight setting, higher TRLHP, etc. The vehicles tested in Kansas City would tend to be high sales volume models. This might explain the 7% difference seen for the US06 cycle, but the differences observed with the other cycles go in the wrong direction. Differences in ambient temperature could explain this difference in fuel economy, as the Kansas City testing was conducted during the late fall and early winter.

We attempted to correct for the difference in temperature using the average temperature for each vehicle's operation, as described above. We then used this average temperature to interpolate between the Bag 2 and Bag 3 fuel economy values measured and 20°F and 75°F, respectively, to estimate a dynamometer-measured fuel economy at the ambient temperature of each vehicle's testing in Kansas City. We cannot perform a similar adjustment to the HFET and US06 fuel economy values as these tests are not run under cold temperature conditions. The results of this adjustment for temperature are shown just below the unadjusted results in Table A-5. As can be seen, for conventional vehicles, this adjustment reduces the difference between the predicted and measured fuel economy values over Bags 2 and 3 from 21-30% to 16-26%, a modest decrease. As described in section II.A.4, we expect the effect of ambient temperature on HFET and US06 fuel economy to be relatively small. Thus, there appears to be factors which are causing onroad fuel consumption to be higher than dynamometer measurements during low speed and mild driving which is not affecting higher speed, more aggressive driving. Generally, this argues for including US06 fuel economy in the fuel economy label calculation. It also supports the inclusion of the 9.5% downward adjustment for non-dynamometer factors.

The comparison for hybrids is similar, but the differences are much more dramatic, particularly at low speed, stop and go driving where hybrid technology functions. Bag 2 and 3 fuel economy measured on the dynamometer exceeds those estimated from onroad measurements by 40-91%. In contrast, at higher speeds, but with either mild or aggressive driving styles, the differences are both smaller and very similar to those found with conventional vehicles. Of course, at higher speeds without much stopping, hybrids operate like conventional vehicles.

As for conventional vehicles, we adjusted the Bag 2 and 3 dynamometer fuel economy values for temperature. The effect is much more dramatic for hybrids, given their greater sensitivity to ambient temperature. The 40-91% difference decreases to 22-46%. These differences are still greater than those found for conventional vehicles. We considered the possibility that our analysis of the data was somehow ignoring the engine shut-off feature of the hybrid vehicles (i.e., the zero fuel consumption occurring during these times were being excluded from the average fuel rates being calculated for lower speed, low power VSP bins). However, we confirmed that our measurements included significant amounts of time when the engine was off. Overall, we measured zero carbon monoxide emissions 12% of the time from the hybrid vehicles. The Prius models had the highest percentage of engine off operation (19%), followed by the Civic (3%), following by the one Insight in the test fleet (1%). Clearly, the Honda hybrids turned off their engines less frequently than the Toyota Prius. This may be due to differences in hybrid technology utilized by the two manufacturers.

We evaluated whether this difference in engine off time affected the comparisons shown in Table A-5. For both the Prius and Civic models, the dynamometer measured fuel economy over Bag 3 is 21% higher than those values estimated from onroad fuel rate measurements, after adjusting for ambient temperature. For Bag 2, the Prius models show a 63% difference, while that for the Civic hybrid models is 38%. Thus, the lower percentage of indicated engine off operation for the Civics is not likely the cause of the greater difference in hybrid fuel economy over Bags 2 and 3 of the FTP shown in Table A-5 for hybrids compared to conventional vehicles. The difference could be due to the efficiency of regenerative braking onroad versus on the dynamometer, as the severity of deceleration is not considered in the VSP methodology. Further study of the data obtained in Kansas City and additional data collected elsewhere in the future will be needed to better identify the cause of the difference. Overall, however, for hybrids, as well as conventional vehicles, the dynamometer measured fuel economy over US06 appears to be much more directly representative of onroad fuel consumption than those measured over the current fuel economy cycles.

Appendix A References

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