National Vehicle and Fuel Emissions Laboratory

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U.S. Department of Transportation

Joint Technical Support Document:

Final Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards

August 2012

Executive Summary

The Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) are issuing a joint final rule to establish new standards for light-duty highway vehicles that will reduce greenhouse gas emissions and improve fuel economy. This joint final rulemaking is consistent with the Presidential Memorandum issued by President Obama on May 21, 2010, requesting that NHTSA and EPA develop through notice and comment rulemaking a coordinated National Program to reduce greenhouse gas emissions and improve the fuel economy of light-duty vehicles for model years 2017-2025. This final rule, consistent with the President's request, responds to the country's critical need to address global climate change and to reduce oil consumption. EPA is regulating greenhouse gas emissions standards under the Clean Air Act, and NHTSA is regulating Corporate Average Fuel Economy standards under the Energy Policy and Conservation Act, as amended. These standards apply to passenger cars, light-duty trucks, and medium-duty passenger vehicles, covering model years 2017 through 2025. They require these vehicles to meet an estimated combined average emissions level of 163 grams of CO_2 per mile in MY 2025 under EPA's GHG program, and 49.6 mpg in MY 2025 under NHTSA's CAFE program and represent a harmonized and consistent national program (National Program). These standards are designed such that compliance can be achieved with a single national vehicle fleet whose emissions and fuel economy performance improves each year from MY2017 to 2025. This document describes the supporting technical analysis for areas of these joint rules which are consistent between the two agencies.

NHTSA and EPA have coordinated closely to create a nationwide joint fuel economy and GHG program based on consistent compliance structures and technical assumptions. To the extent permitted under each Agency's statutes, NHTSA and EPA have incorporated the same compliance flexibilities, such as averaging, banking, and trading of credits, off-cycle credits, and the same testing protocol for determining the agencies' respective fleet-wide average final standards. In addition, the agencies have worked together to create a common baseline fleet and to harmonize most of the costs and benefit inputs used in the agencies' respective modeling processes for this joint final rule.

Chapter 1 of this joint TSD provides an explanation of the agencies' methodology used to develop the baseline and reference case vehicle fleets, including the technology composition of these fleets, and how the agencies projected vehicle sales into the future. One of the fundamental features of this technical analysis is the development of these fleets, which are used by both agencies in their respective models. In order to determine technology costs associated with this joint rulemaking, it is necessary to consider the vehicle fleet absent a rulemaking as a "business as usual" comparison. In past CAFE rulemakings, NHTSA has used confidential product plans submitted by vehicle manufacturers to develop the reference case fleet. In responding to comments from these previous rulemakings that the agencies make these fleets available for public review, the agencies created a new methodology for creating baseline and reference fleets using data, the vast majority of which is publicly available.

Chapter 2 of this document discusses how NHTSA and EPA developed the mathematical functions which provide the bases for the final car and truck standards. NHTSA and EPA worked together closely to develop regulatory approaches that are fundamentally the same, and have chosen to use an attribute-based program structure based on the footprint attribute, similar to the mathematical functions used in the MYs 2012-2016 rule. The agencies revisited other attributes as candidates for the standard functions, but concluded that footprint remains the best option for balancing the numerous technical and social factors. However, the agencies did adjust the shape of the truck footprint curve, in comparison to the MYs 2012-2016 rule. The agencies also modified the way the car and truck curves change from year to year compared to the MYs 2012-2016 rule. In determining the shape of the footprint curve, the agencies considered factors such as the magnitudes of CO_2 reduction and fuel savings, how much that shape may incentivize manufacturers to comply in a manner which circumvents the overall goals of the joint program, whether the standards' stringencies are technically attainable, the utility of vehicles, and the mathematical flexibilities inherent to the statistical fitting of such a function.

Chapter 3 contains a detailed analysis of NHTSA and EPA's technology assumptions on which the final regulations were based. Because the majority of technologies that reduce GHG emissions and improve fuel economy are identical, it was crucial that NHTSA and EPA use common assumptions for values pertaining to technology availability, cost, and effectiveness. The agencies collaborated closely in determining which technologies would be considered in the rulemaking, how much these technologies would cost the manufacturers (directly) in the time frame of the final rule, how these costs will be adjusted for learning as well as for indirect cost multipliers, and how effective the technologies are at accomplishing the goals of improving fuel efficiency and GHG emissions.

Chapter 4 of this document provides a full description and analysis of the economic factors considered in this joint final rule. EPA and NHTSA harmonized many inputs capturing economic and social factors, such as the discount rates, fuel prices, social costs of carbon, the magnitude of the rebound effect, the value of refueling time, and the social cost of importing oil and fuel.

Chapter 5 of this joint TSD discusses adjustments and credits to reflect technologies that improve air conditioner efficiency, that improve efficiency under other off-cycle driving conditions, and that reduce leakage of air conditioner refrigerants that contribute to global warming. The air conditioner credits are similar to the MYs 2012-2016 rule, with two notable exceptions: NHTSA is allowing A/C efficiency improvements to help come into compliance with fuel economy standards, and a new air conditioner test procedure is introduced to help capture efficiency credits. NHTSA is now also allowing off-cycle improvements to help manufacturers come into compliance with fuel economy standards. A list of some technologies and their credits and a streamlined methodology is provided by the agencies to help simplify the credit generating process. Chapter 5 also discusses adjustments to encourage "game changing" technologies (such as hybridized powertrains) for full-size pickup trucks.

Chapter 1: The Baseline and Reference Vehicle Fleets

The passenger cars and light trucks sold currently in the United States, and those that are anticipated to be sold in the MYs 2017-2025 timeframe, are highly varied and satisfy a wide range of consumer needs. From two-seater miniature cars to 11-seater passenger vans to large extended cab pickup trucks, American consumers have a great number of vehicle options to accommodate their needs and preferences. Recent volatility in oil prices and the state of the economy have demonstrated that consumer demand and choice of vehicles within this wide range can be sensitive to these factors. Although it is impossible to precisely predict the future, the agencies need to characterize and quantify the future fleet in order to assess the impacts of rules that would affect that future fleet. The agencies have examined various publicly-available sources, and then used inputs from those sources in a series of models to project the composition of baseline and reference fleets for purposes of this analysis. This chapter describes this process, and the characteristics of each of the two baseline and reference fleets.

The agencies have made every effort to make this analysis transparent and duplicable. Because both the input and output sheets from our modeling are public,[1] stakeholders can verify and check NHTSA's and EPA's modeling results, and perform their own analyses with these datasets.

1.1 Why do the agencies establish baseline and reference vehicle fleets?

In order to calculate the impacts of the final GHG and CAFE standards, it is necessary to estimate the composition of the future vehicle fleet absent the new standards. EPA and NHTSA have developed a baseline/reference fleet in two parts. The first step was to develop a "baseline" fleet. The agencies create a baseline fleet in order to track the volumes and types of fuel economy-improving and CO_2-reducing technologies that are already present in the existing vehicle fleet. Creating a baseline fleet helps to keep, to some extent, the agencies' models from adding technologies to vehicles that already have these technologies, which would result in "double counting" of technologies' costs and benefits. The second step was to project the baseline fleet sales into MYs 2017-2025. This is called the "reference" fleet, and it represents the fleet volumes (but, until later steps, not additional levels of technology) that the agencies believe would exist in MYs 2017-2025 absent any change due to regulation in 2017-2025.

After determining the reference fleet, a third step is needed to account for technologies (and corresponding increases in cost and reductions in fuel consumption and CO_2 emissions) that could be added to the baseline technology vehicles in the future, taking into account previously-promulgated standards, and assuming MY 2016 standards apply at the same levels through MY 2025. This step uses the OMEGA and CAFE models to add technologies to vehicles in each of the baseline market forecasts such that each manufacturer's car and truck CAFE and average CO_2 levels reflect MY 2016 standards. The models' output, the "reference case", is the light-duty fleet estimated to exist in MYs 2017-2025 without new GHG/CAFE standards. All of the agencies' estimates of emission reductions/fuel economy improvements, costs, and societal impacts for purposes of this final rulemaking (FRM) are developed in relation to the agencies' reference cases. This chapter describes the first two steps of the development of the baseline and reference fleets. The third step of technology addition is developed separately by each agency as the outputs of the OMEGA and CAFE models (see Chapter 3 of the TSD for an explanation of how the models apply technologies to vehicles in order to evaluate potential paths to compliance).

1.2 The 2008 and 2010 based vehicle fleet projections

1.2.1 Why did the agencies develop two fleet projections for the final rule?

Although much of the discussion in this and following sections describes the methodology for creating a single baseline and reference fleet, for this final rule the agencies actually developed two baseline and reference fleets. In the NPRM, the agencies used 2008 MY CAFE certification data to establish the "2008-based fleet projection." [a] The agencies noted that MY 2009 CAFE certification data was not likely to be representative since it was so dramatically influenced by the economic recession (Joint Draft TSD section 1.2.1). The agencies further noted that MY 2010 CAFE certification data might be available for use in the final rulemaking for purposes of developing a baseline fleet (id.). The agencies also stated that a copy of the MY 2010 CAFE certification data would be put in the public docket if it became available during the comment period. The MY 2010 data was reported by the manufacturers throughout calendar year 2011 as the final sales figures were compiled and submitted to the EPA database. Due to the lateness of the CAFE data submissions[b], it was not possible to submit the new 2010 data into the docket during the public comment period. As explained below, however, consistent with the agencies' expectations at proposal, and with the agencies' standard practice of updating relevant information as practicable between proposals and final rules, the agencies are using these data in one of the two fleet-based projections we are using to estimate the impacts of the final rules.

For analysis supporting the NPRM, the agencies developed a forecast of the light vehicle market through MY 2025 based on (a) the vehicle models in the MY 2008 CAFE certification data, (b) the AEO2011 interim projection of future fleet sales volumes, and (c) the future fleet forecast conducted by CSM in 2009. In the proposal, the agencies stated we planned to use MY 2010 CAFE certification data, if available, for analysis supporting the final rule (Joint Draft TSD, p. 1-2). The agencies also indicated our intention to, for analysis

[a] 2008 based fleet projection is a new term that is the same as the reference fleet. The term is added to clarify when we are using the 2008 baseline and reference fleet vs. the 2010 baseline and reference fleet.

[b] Partly due to the earthquake and tsunami in Japan and the significant impact this had on their facilities, some manufacturers requested and were granted an extension on the deadline to submit their CAFE data.

supporting the final rule, use the most recent version of EIA's AEO, and a market forecast updated relative to that purchased from CSM (Joint Draft TSD section 1.3.5).

For this final rulemaking, the agencies have analyzed the costs and benefits of the standards using two different forecasts of the light vehicle fleet through MY 2025. The agencies have concluded that the significant uncertainty associated with forecasting sales volumes, vehicle technologies, fuel prices, consumer demand, and so forth out to MY 2025, makes it reasonable and appropriate to evaluate the impacts of the final CAFE and GHG standards using two baselines. One market forecast, similar to the one used for the NPRM, uses corrected data regarding the MY2008 fleet, information from AEO 2011, and information purchased from CSM. The agencies received comments regarding the market forecast used in the NPRM suggesting that updates in several respects could be helpful to the agencies' analysis of final standards; given those comments and since the agencies were already planning to produce an updated market forecast, the final rule also contains another market forecast using MY 2010 CAFE certification data, information from AEO 2012, and information purchased from LMC Automotive (formerly JD Power Forecasting).

The two market forecasts contain certain differences, although as will be discussed below, the differences are not significant enough to change the agencies' decision as to the structure and stringency of the final standards. For example, MY 2008 certification data represents the most recent model year for which the industry's offerings were not strongly affected by the subsequent economic recession, which may make it reasonable to use if we believe that the future vehicle model offerings are more likely to be reflective of pre-recession offerings than models produced after MY 2008 (*e.g.*, in MY 2010). Also, the MY 2010-based fleet projection employs a future fleet forecast provided by LMC Automotive, which is more current than the projection provided by CSM in 2009. However, the CSM forecast, utilized for the MY2008-based fleet projection, was influenced by the recession, particularly in predicting major declines in market share for some manufacturers (*e.g.*, Chrysler) which the agencies do not believe are reasonably reflective of future trends.

The MY 2010 based fleet projection, which is used in EPA's alternative analysis and in NHTSA's co-analysis, employs a future fleet forecast provided by LMC Automotive, which is more current than the projection provided by CSM in 2009, and which reflects the post-proposal MY 2010 CAFE certification data. However, this MY 2010 CAFE data also shows strong effects of the economic recession. For example, industry-wide sales were down by 20% compared to pre-recession MY 2008 levels. For some companies like Chrysler, Mitsubishi, and Subaru, sales were down by 30-40% from MY 2008 levels.[c] For BMW, General Motors, Jaguar/Land Rover, Porsche, and Suzuki, sales were down more than 40% from MY 2008 levels.[d] Employing the MY 2008 vehicle data avoids using these baseline

[c] These figure are arrived at using Table 1-17 and Table 1-39.

market shifts when projecting the future fleet. On the other hand, it also perpetuates vehicle brands and models (and thus, their outdated fuel economy levels and engineering characteristics) that have since been discontinued. The MY 2010 CAFE certification data accounts for the phase-out of some brands (*e.g.*, Saab, Pontiac, Hummer)[e] and the introduction of some technologies (*e.g.*, Ford's Ecoboost engine), which may be more reflective of the future fleet in this respect.

Thus, given the volume of information that goes into creating a baseline forecast and given the significant uncertainty in any projection out to MY 2025, the agencies think that a reasonable way to illustrate the possible impacts of that uncertainty for purposes of this rulemaking is the approach taken here of analyzing the effects of the final standards under both the MY 2008-based baseline and the MY 2010-based baseline. The agencies' analyses are presented in our respective RIAs and preamble sections.

1.3 The 2008 Based Fleet Projection

Differences between the 2008 MY based fleet used in the final rule compared to that used in the NPRM include minor corrections to some of the vehicle footprint data, and minor corrections to technology "overrides" and technology class assignments used in DOT's modeling system. A discussion of the changes is in the section below along with a thorough description of how the projection was created.

1.3.1 On what data is the MY2008 baseline vehicle fleet based?

As part of the CAFE program, EPA measures vehicle CO_2 emissions and converts them to mpg, and generates and maintains the federal fuel economy database. See 49 U.S.C 32904 and 40 CFR Part 600. Most of the information about the vehicles that make up the 2008 fleet was gathered from EPA's emission certification and fuel economy database, most of which is available to the public. These data (by individual vehicle model produced in MY 2008) include: vehicle production volume, fuel economy rating for CAFE certification (*i.e.*, on the 2-cycle city-highway test), carbon dioxide emissions (equivalent to fuel economy rating for CAFE certification), fuel type (gasoline, diesel, and/or alternative fuel), number of engine cylinders, displacement, valves per cylinder, engine cycle, transmission type, drive (rear-wheel, all-wheel, etc.), hybrid type (if applicable), and engine aspiration (naturally-aspirated, turbocharged, etc.). In addition to this information about each vehicle model produced in MY 2008, the agencies need additional information about the fuel economy-improving/CO_2-reducing technologies already on those vehicle models in order to assess how much and which technologies to apply to determine a path toward future compliance. However, EPA's certification database does not include a detailed description of the types of technologies considered in this FRM because this level of information was not reported in

[e] Based on our review of the CAFE certification data, the MY 2010-based fleet contains no Saabs, and compared to the MY 2008-based fleet, about 90% fewer Hummers and about 75% fewer Pontiacs.

MY 2008 for emission certification or fuel economy testing. Thus, the agencies augmented this description with publicly-available data which includes more complete technology descriptions from Ward's Automotive Group.[f,g] The agencies also required information about the footprints of MY 2008 vehicles in order to generate potential target footprint curves (as discussed in Chapter 2 of the TSD). In a few instances when relevant vehicle information (such as vehicle track width for footprint) was not available from these two sources, the agencies obtained this information principally from publicly-accessible internet sites such as Motortrend.com or Edmunds.com, and occasionally from other sources (such as articles about specific vehicles revealed from internet search engine research).[h,i]

Between the NPRM and the final rule, the agencies found discrepancies in footprint values for a number of vehicles in the MY 2008 CAFE certification data. Specifically, contractors to DOT employed to develop a market share model for incorporation into the CAFE model noted that out of 1,302 vehicles in the MY 2008-based input file used in the agencies' NPRM analysis, in 554 cases, the wheelbase value in the CAFE certification data did not match wheelbase data from Ward's Automotive that the contractor had obtained separately. While wheelbase is not a direct input to the models used in developing the standards, it is a component of footprint, which is a key input in the modeling process.

Of the reported differences, 287 (51.8%) were less than or equal to 0.1 inch, and 115 (20.8%) were greater than 0.1 inch but less than or equal to 0.5 inch. The former set of differences is most likely attributable to differences in the number of significant digits in the reported raw data. The latter set of differences may also be due to reporting differences or actual measurement differences, but would not have a significant impact on the computed footprint value, all other things being equal. These differences were not considered further.

Of the remaining differences, 14 (2.5%) were greater than 0.5 inch but less than 1 inch. Most significantly, 138 (24.9%) of the differences were greater than 1 inch, ranging in value from 1.1 inch to 23.8 inches.

To verify these findings, the Ward's data used by the contractor on wheelbase for the 152 vehicles with a discrepancy greater than 0.5 inches were compared to wheelbase data from Edmunds, cars.com, Motor Trend, and product plans where available, and values reflecting the agencies' best judgment about actual average values was selected.

Footprint for the 152 vehicles was thus recalculated based on corrected wheelbase. In the process of validating the wheelbase data, the agencies noted that there were many

[f] WardsAuto.com: Used as a source for engine specifications shown in Table 1-1.
[g] Note that WardsAuto.com, where this information was obtained, is a fee-based service, but all information is public to subscribers.
[h] Motortrend.com and Edmunds.com: Used as a source for footprint and vehicle weight data.
[i] Motortrend.com and Edmunds.com are free, no-fee internet sites.

discrepancies in the track width values, which the agencies also corrected in the calculation of the corrected footprints.

The affected vehicles included those of the following manufacturers:

Chrysler – 4 (2 large SUV, 2 small SUV)
Daimler – 19 (1 compact auto, 15 large auto, 1 midsize auto, 2 subcompact auto)
Ford – 4 (2 large pickup, 2 small pickup)
General Motors – 29 (18 compact auto, 7 midsize auto, 4 subcompact auto)
Honda – 17 (3 compact auto, 2 large SUV, 8 midsize auto, 1 small pickup, 3 subcompact auto)
Hyundai – 2 (2 subcompact auto)
Kia – 8 (2 compact auto, 4 midsize auto, 2 subcompact auto)
Mazda – 7 (4 midsize SUV, 2 small pickup, 1subcompact auto)
Nissan – 11 (4 compact auto, 6 large auto, 1 minivan)
Subaru – 15 (6 midsize auto, 9 midsize SUV)
Tata – 2 (2 midsize auto)
Toyota – 29 (3 compact auto, 6 large pickup, 16 large auto, 4 midsize auto)
Volkswagen – 5 (4 large auto, 1 midsize auto)

Table 1-1 shows the change from the NPRM to the FRM in the average footprint for all vehicles, cars, and trucks. The average change in footprint was very small, although quite a few vehicles' footprints were updated.

Table 1-1 2008 MY Footprint changes (Final Rule Values – NPRM Values)

Average Footprint of all Vehicles	Average Footprint Cars	Average Footprint Trucks
-0.1	-0.2	0

The baseline vehicle fleet for the analysis informing these final rules is the same except for the footprint changes to the baseline vehicle fleet used in the MYs 2012-2016 rulemaking, and like that baseline, is comprised of publicly-available data to the largest extent possible. Some of the technology data included in the MYs 2012-2016 analysis' baseline fleet was based on confidential product plan information about MY 2008 vehicles, specifically, data about which vehicles already have low friction lubricants, electric power steering, improved accessories, and low rolling resistance tires applied, the agencies no longer consider that information as needing to be withheld, because by now all MY 2008 vehicle models are already in the on-road fleet. As a result, the agencies are able to make public the exact baseline used in this rulemaking analysis.

As explained in the MYs 2012-2016 TSD, creating the 2008 baseline fleet Excel file was an extremely labor-intensive process. EPA in consultation with NHTSA first considered using EPA's CAFE certification data, which contains most of the required information. However, since the deadline for manufacturers to report this data did not allow enough time, in the MYs 2012-2016 rulemaking, for early modeling review, the agencies began to create the baseline fleet file using an alternative data source.

The agencies ultimately relied on a combination of EPA's vehicle emissions certification data, data from a paid subscription to Ward's Automotive Group, and CAFE certification data. EPA's vehicle emissions certification data contains much of the information required for creating a baseline fleet file, but it lacked the production volumes that are necessary for the OMEGA and Volpe models, and also contains some vehicle models that manufacturers certified but did not produce in MY 2008. The data from Ward's contained production volumes (which were not ultimately used, because they did not have volumes for individual vehicles down to the resolution of the specific engine and transmission level) and vehicle specifications, and eliminated extraneous vehicles.

The EPA vehicle emissions certification dataset came in two parts, an engine file and a vehicle file, which the agencies combined into one spreadsheet using their common index. The more-specific Ward's data also came in two parts, an engine file and a vehicle file, and also required mapping, which was more difficult than combining the EPA vehicle emissions certification dataset files because there was no common index between the Ward's files. A new index was implanted in the engine file and a search equation in the vehicle file, which identified most of the vehicle and engine combinations. Each vehicle and engine combination was reviewed and corrections were made manually when the search routine failed to give the correct engine and vehicle combination. The combined Ward's data was then mapped to the EPA vehicle emissions certification data by creating a new index in the combined Ward's data and using the same process that was used to combine the Ward's engine and vehicle files.

In the next step, CAFE certification data had to be merged in order to fill out the needed production volumes. NHTSA and EPA reviewed the CAFE certification data for MY 2008 as it became available in the MYs 2012-2016 rulemaking. The CAFE certification set could have been used with the Ward's data without the EPA vehicle emission certification data set, but was instead appended to the combined Ward's and EPA vehicle emission certification dataset. That combined dataset was then mapped into the CAFE dataset using the same Excel mapping technique described above. Finally EPA and NHTSA obtained the remaining attribute and technology data, such as footprint, curb weight, and others (for a complete list of data with sources see Table 1-2 below) from other sources, thus completing the baseline dataset.

Another step that was done for the first time in the NPRM (and used in this FRM baseline as well) was to disaggregate the footprints of pickup trucks. In the MYs 2012-2016 rulemaking the agencies aggregated full-size pickup data in the baseline by using average values to represent all variants of a given pickup line. While full-size pickups might be offered with various combinations of cab style (*e.g.*, regular, extended, crew) and box length (*e.g.*, 5 ½', 6 ½', 8'), and therefore multiple footprint sizes, CAFE compliance data for MY 2008 did not contain footprint information, and therefore could not reliably be used to identify which pickup entries correspond to footprint values estimable from public or commercial sources. Therefore, the agencies used the known production levels of average values to represent all variants of a given pickup line (*e.g.*, all variants of the F-150, or all variants of the Sierra/Silverado) in order to calculate the sales-weighted average footprint/fuel economy value for each pickup family. In retrospect, this may have affected how we fit the light truck target curve, among other things, so the agencies have since created an expanded version of the fleet to account for the variation in footprint/wheelbase for the large pickups of Chrysler, Ford, GM, Nissan and Toyota. In MY 2008, large pickups were available from Nissan with 2, Chrysler and Toyota with 3, and Ford and GM with 5 wheelbase/footprint combinations. The agencies got this footprint data from MY 2008 product plans submitted by the various manufacturers, which can be made public at this time because by now all MY 2008 vehicle models are already in production, which makes footprint data about them essentially public information.

The agencies created the expanded fleet by replicating original records from a single pickup footprint model into multiple pickup models with distinct footprint values, in order to reflect the additional pickup model footprints just noted. For example, an F-150 in the MY 2008 baseline used in the MYs 2012-2016 rulemaking analysis with a footprint value of 67 square feet, is disaggregated by replicating 2 times in all respects, except with footprint values of 58, 67, and 73 square feet. Sales volumes of these pickups from the original record were distributed to each of the “58 square feet” and “73 square feet” duplicates based on the distribution of MY 2008 sales by these pickups’ wheelbase/footprint, which the agencies took from product plan data submitted by the manufacturers in 2008/2009 in response to requests to support the MYs 2012-2016 rulemaking analysis. The agencies were able to distribute the sales for each of the original pickups by wheelbase/footprint by matching each of the pickups in the baseline fleet with pickups in the product plans on the basis of drive type, transmission type, and engine displacement, cylinders/configuration and HP, and then sorting and summing the sales of the matched pickups in the product plans by wheelbase/footprint.

Both agencies used this fleet forecast to populate input files for the agencies’ respective modeling systems. The structure of the market forecast input file used for the Volpe model is described the model documentation.[2] To help readers who wish to directly examine the baseline fleet file for EPA’s OMEGA model, and to provide some idea of its contents for those readers who do not, Table 1-2 shows the columns of the complete fleet file, which includes the MY 2008 baseline data that was compiled. Each column has its name, definition (description) and source. Most elements shown in Table 1-2 also appear in the market forecast input file for DOT’s modeling system, which also accommodates some additional data elements discussed in the model documentation.

Table 1-2 2008 MY Data, Definitions, and Sources

Data Item	Definition	Where The Data is From
Index	Index Used to link EPA and NHTSA baselines	Created
Manufacturer	Common name of company that manufactured vehicle. May include more name plates than Cert Manufacturer Name.	Certification data
CERT Manufacturer Name	Certification name of company that manufactured vehicle	Certification data
Name Plate	Name of Division	Certification data

Model	Name of Vehicle	Certification data
Reg Class	EPA Fuel Economy Class Name	Certification data
Our Class	If a car's Footprint<43 then "SubCmpctAuto" If a car's 43<=Footprint<46 then "CompactAuto" If a car's 46<=Footprint<53 then "MidSizeAuto" If a car's Footprint >=53 then "LargeAuto" If a S.U.V.'s Footprint < 43 then "SmallSuv" If a S.U.V.'s 43<=Footprint<46 then "MidSizeSuv" If a S.U.V's Footprint >=46 then "LargeSuv" If a Truck's Footprint < 50 then "SmallPickup" If a Truck's Footprint>=50 then "LargPickup" If a Van's Structure is Ladder then "CargoVan" If a Van's Structure is Unibody then "Minivan"	Derived From Certification data and Footprint
CSM Class	CSM Worldwide's class for the vehicle. Used to weight vehicles based on CSM data.	CSM Worldwide
Vehicle Type Number	Vehicle Type Number assigned to a vehicle based on its number of cylinders, valves per cylinder, and valve actuation technology	Defined by EPA staff
Vehicle Index From Sum Page	Number to be used as a cross reference with the Sum Pages.	NA
Traditional Car/Truck	Traditional Car Truck value for reference.	Certification data
NHTSA Defined New Car/Truck	New NHTSA Car Truck value as defined in 2011 Fuel economy regulations. Used in calculations.	NHTSA
Total Production Volume	Total number of vehicles produced for that model.	Certification data
Fuel Econ. (mpg)	EPA Unadjusted Fuel Economy	Certification data
CO2	CO2 calculated from MPG. CO2 weighted 1.15 times higher for diesel vehicles.	Certification data
Area (sf)	Average Track x Wheelbase	Calculated from track width and wheel base
Fuel	Gas or Diesel	Wards
Fuel Type	Gas or Diesel or Electric	Certification data
Disp (lit.)	Engine Cylinder Displacement Size in Liters	Wards/Certification data
Effective Cyl	Number of Cylinder + 2 if the engine has a turbo or super charger.	Derived From Certification data.
Actual Cylinders	Actual Number of Engine Cylinders	Certification data
Valves Per Cylinder	Number of Valves Per Actual Cylinder	Certification data
Valve Type	Type of valve actuation.	Wards (Note: Type E is from Cert Data)
Valve Actuation	Type of valve actuation with values compatible with the package file.	Wards
VVT	Type of valve timing with values compatible with the package file.	Wards
VVLT	Type of valve lift with values compatible with the package file.	Wards
Deac	Cylinder Deactivation with a value that is compatible with the package file.	Wards
Fuel injection system	Type of fuel injection.	Wards
Boost	Type of Boost if any.	Wards
Engine Cycle	As Defined by EPA Cert. Definition	Wards

Horsepower	Max. Horsepower of the Engine	Wards
Torque	Max. Torque of the Engine	Wards
Trans Type	A=Auto AMT=Automated Manual M=Manual CVT= Continuously Variable Transmission	Certification data
Trans	Type Code with number of Gears	Certification data
Num of Gears	Number of Gears	Certification data
Transmission	Transmission definition. Matches the cost definition.	Certification data
Structure	Ladder or Unibody	General Internet Searches
Drive	Fwd, Rwd, 4wd	Certification data
Drive with AWD	Fwd, Rwd, Awd, 4wd	Certification data
Wheelbase	Length of Wheelbase	Some from Edmunds.com or Motortrend.com, Others from product plans with a subset verified with Edmunds.com or Motortrend.com for accuracy.
Track Width (front)	Length of Track Width in inches	Some from Edmunds.com or Motortrend.com, Others from product plans with a subset verified with Edmunds.com or Motortrend.com for accuracy.
Track Width (rear)	Length of Track Width in inches	Some from Edmunds.com or Motortrend.com, Others from product plans with a subset verified with Edmunds.com or Motortrend.com for accuracy.
Footprint: PU Average	Car and Large Truck Footprints are normal (Average Track x Wheelbase). Medium and Small Truck footprints are the production weighted average for each vehicle.	Derived from data from Edmunds.com or Motortrend.com. Production volumes or specific footprints from product plans.
Threshold FootPrint	Footprint valve that will be set to 41 for values less than 41, Will be set to 56 for car values > 56, and will be set to 74 for truck values >74	Derived from data from Edmunds.com or Motortrend.com. Production volumes or specific footprints from product plans.
Curb Weight	Curb Weight of the Vehicle	Some from Edmunds.com or Motortrend.com, Others from product plans with a subset verified with Edmunds.com or Motortrend.com for accuracy.
GVWR	Gross Vehicle Weight Rating of the Vehicle	Some from Edmunds.com or Motortrend.com, Others from product plans with a subset verified with Edmunds.com or Motortrend.com for accuracy.
Stop-Start/Hybrid/Full EV	Type of Electrification if any. Blank = None	Certification data
Import Car	Cars Imported	Certification data
Towing Capacity (Maximum)	Weight a vehicle is rated to tow.	Volpe Input File
Engine Oil Viscosity	Ratio between the applied shear stress and the rate of shear, which measures the resistance of flow of the engine oil (as per SAE Glossary of Automotive Terms)	Volpe Input File
Volume 2009	Projected Production Volume for 2009	Calculated based on 2008 volume and Annual Energy Outlook and CSM adjustment factors.
Volume 2010	Projected Production Volume for 2010	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2011	Projected Production Volume for 2011	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2012	Projected Production Volume for 2012	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2013	Projected Production Volume for 2013	Calculated based on 2008 volume and AEO and CSM adjustment factors.

Volume 2014	Projected Production Volume for 2014	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2015	Projected Production Volume for 2015	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2016	Projected Production Volume for 2016	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2017	Projected Production Volume for 2017	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2018	Projected Production Volume for 2018	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2019	Projected Production Volume for 2019	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2020	Projected Production Volume for 2020	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2021	Projected Production Volume for 2021	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2022	Projected Production Volume for 2022	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2023	Projected Production Volume for 2023	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2024	Projected Production Volume for 2024	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Volume 2025	Projected Production Volume for 2025	Calculated based on 2008 volume and AEO and CSM adjustment factors.
Low drag brakes	See Volpe Documentation	Volpe Input File
Electric Power steering	See Volpe Documentation	Volpe Input File
Volpe Index	Number used to reorder the vehicles in the EPA baseline in the same order as the Volpe input file.	Volpe Input File

Notes:
1. For engines not available in the WardsAuto.com engine file, an internet search was done to find this information.
2. These data were obtained from manufacturer's product plans. They were used to block (where possible) the model from adding technology that was already on a vehicle.
3. Ward's Automotive Group data obtained from "2008 Light Vehicle Engines."

DOT's CAFE model also uses a series of inputs—referred to as "overrides"—to specify baseline technology content of specific vehicle models (and specific engines and transmissions) and to indicate cases where specific technologies are not applicable to specific vehicle models. In the MY 2008-based market forecast, DOT has corrected some of these settings to indicate that micro-hybrid technology (or more advanced hybrid) is already present on hybrid versions of the Altima, Aura, Civic, Camry, Escape, Highlander, Lexus GS and LS, Lexus RX, Mariner, Malibu, Prius, Tahoe, Tribute, Vue, and Yukon. The CAFE model also uses inputs to assign vehicles to specific "technology classes," where technology-related inputs define the applicability, efficacy, and cost of each technology for vehicles in each technology class. In the MY 2008-based market forecast, DOT has reassigned the Altima (coupe), Audi A4, Corolla, Impala, Matrix, Passat, and Jetta to technology classes that better represent these vehicles' size and performance characteristics.

The sales volumes for the MY 2008 baseline fleet are included in the section below on reference fleet under the MY 2008 columns. Table 1-3 displays the engine technologies present in the baseline fleet. Again, the engine technologies for the vehicles manufactured by these manufacturers in MY 2008 were largely obtained from Ward's Auto online.

Table 1-3 2008 Engine Technology Percentages

Manufacturer	Vehicle Type	Turbo Charged	Super Charged	Single Overhead Cam	Dual Overhead Cam	Overhead Cam	Variable Valve Timing Continuous	Variable Valve Timing Discrete	Variable Valve Timing Intake Only	Variable Valve Lift and Timing Continuous	Variable Valve Lift and Timing Discrete	Cylinder Deactivation	Direct Injection
All	Both	3%	0%	20%	63%	17%	8%	22%	30%	0%	12%	6%	5%
All	Cars	4%	0%	17%	73%	9%	9%	24%	35%	0%	13%	3%	7%
All	Trucks	1%	0%	24%	48%	29%	6%	19%	23%	0%	10%	11%	3%
Aston Martin	Cars	0%	0%	0%	100%	0%	0%	100%	0%	24%	0%	0%	0%
Aston Martin	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BMW	Cars	33%	1%	14%	86%	0%	14%	86%	0%	0%	13%	0%	33%
BMW	Trucks	5%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	6%
Chrysler/Fiat	Cars	1%	0%	21%	72%	8%	0%	42%	0%	0%	0%	5%	0%
Chrysler/Fiat	Trucks	0%	0%	39%	4%	57%	0%	4%	0%	0%	0%	4%	0%
Daimler	Cars	2%	0%	55%	45%	0%	72%	4%	13%	0%	0%	0%	2%
Daimler	Trucks	16%	1%	36%	64%	0%	35%	17%	47%	0%	0%	0%	16%
Ferrari	Cars	0%	0%	0%	100%	0%	0%	100%	0%	29%	0%	0%	0%
Ferrari	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ford	Cars	0%	1%	15%	85%	0%	4%	0%	47%	0%	0%	0%	0%
Ford	Trucks	0%	0%	65%	32%	3%	28%	1%	9%	0%	0%	0%	0%
Geely/Volvo	Trucks	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%
Geely/Volvo	Cars	49%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%
GM	Trucks	0%	0%	0%	31%	69%	5%	17%	14%	0%	0%	40%	0%
GM	Cars	1%	0%	0%	56%	44%	29%	31%	1%	0%	0%	4%	6%
Honda	Cars	0%	0%	57%	43%	0%	0%	27%	20%	0%	100%	11%	0%
Honda	Trucks	4%	0%	64%	36%	0%	0%	4%	28%	0%	100%	0%	4%
Hyundai	Cars	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Hyundai	Trucks	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Kia	Cars	0%	0%	0%	100%	0%	0%	0%	10%	0%	0%	0%	0%
Kia	Trucks	0%	0%	0%	100%	0%	0%	0%	17%	0%	0%	0%	0%
Lotus	Cars	0%	77%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%
Lotus	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mazda	Cars	11%	0%	0%	99%	0%	0%	7%	92%	0%	0%	0%	11%

Mazda	Trucks	24%	0%	1%	99%	0%	0%	13%	87%	0%	0%	0%	24%
Mitsubishi	Cars	6%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Mitsubishi	Trucks	0%	0%	100%	0%	0%	38%	0%	0%	0%	0%	0%	0%
Nissan	Cars	0%	0%	0%	100%	0%	0%	4%	96%	0%	0%	0%	0%
Nissan	Trucks	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Porsche	Cars	17%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	17%
Porsche	Trucks	12%	0%	0%	100%	0%	0%	100%	0%	0%	100%	0%	100%
Spyker/Saab	Cars	100%	0%	0%	100%	0%	0%	17%	0%	0%	0%	0%	0%
Spyker/Saab	Trucks	0%	0%	0%	62%	38%	0%	0%	62%	0%	0%	28%	0%
Subaru	Cars	15%	0%	69%	31%	0%	0%	0%	31%	0%	1%	0%	0%
Subaru	Trucks	3%	0%	70%	30%	0%	0%	23%	7%	0%	27%	0%	0%
Suzuki	Cars	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Suzuki	Trucks	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%
Tata/JLR	Cars	0%	0%	0%	100%	0%	0%	76%	24%	0%	0%	0%	0%
Tata/JLR	Trucks	0%	20%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Tesla	Cars	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tesla	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	Cars	0%	0%	0%	100%	0%	0%	29%	71%	0%	0%	0%	8%
Toyota	Trucks	0%	0%	0%	100%	0%	0%	61%	39%	0%	0%	0%	6%
Volkswagen	Cars	43%	0%	85%	15%	0%	0%	48%	0%	0%	1%	0%	89%
Volkswagen	Trucks	1%	0%	0%	100%	0%	0%	99%	0%	0%	79%	0%	100%

The data in Table 1-3 indicates that manufacturers had already begun implementing a number of fuel economy/GHG reduction technologies in the baseline (2008) fleet. For example, VW stands out as having a significant number of turbocharged direct injection engines, though it is uncertain whether their engines are also downsized. Some of the valve and cam technologies are quite common in the baseline fleet: for example, nearly half the baseline fleet already has dual cam phasing, while Honda and GM have considerable levels of engines with cylinder deactivation. Honda also has already implemented continuously variable valve lift on a majority of their engines. Part of the implication of these technologies already being present in the baseline is that if manufacturers have already implemented them, they are therefore not available in the rulemaking analysis for improving fuel economy and reducing CO_2 emissions further, requiring the agencies to look toward increasing penetration of these and other technologies and increasingly advanced technologies to project continued improvements in stringency over time.

The section below provides further detail on the conversion of the MY 2008 baseline into the MYs 2017-2025 reference fleet. It also describes more of the data contained in the baseline spreadsheet.

1.3.2 The MY 2008 Based MY 2017-2025 Reference Fleet

The reference fleet aims to reflect the current market conditions and expectations about conditions of the vehicle fleet during the model years to which the agencies' rules apply. Fundamentally, constructing this fleet involved projecting the MY 2008 baseline fleet into the MYs 2017-2025 model years. It also included the assumption that none of the vehicle models had changes during this period. Projecting this future fleet is a process that is necessarily uncertain. NHTSA and EPA therefore relied on many sources of reputable information to make these projections.

1.3.2.1 On what data is the reference vehicle fleet based (using the 2008 baseline)?

For the MY 2008-based reference fleet, EPA and NHTSA have based the projection of total car and light truck sales on the 2011 projections made by the Energy Information Administration (EIA). EIA publishes a projection of national energy use annually called the Annual Energy Outlook (AEO).[3] EIA issued an early release version of AEO2012 January 2012. The agencies are continuing to use this AEO data for the MY 2008 baseline consistent with the NPRM. EPA and NHTSA are employing the newer version of AEO in projecting the reference fleet for the 2010 MY based baseline and reference fleet projection as discussed in section 1.4.2.1.

As in the NPRM, the agencies used the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS) to estimate the future relative market shares of passenger cars and light trucks. However, NEMS shifts the market toward passenger cars in order to ensure compliance with EISA's requirement that CAFE standards cause the fleet to achieve 35 mpg by 2020. Because we use our market projection as a baseline relative to which we measure the effects of new standards, and we attempt to estimate the industry's ability to comply with new standards without changing product mix (*i.e.*, we analyze the effects of the final rules assuming manufacturers will not change fleet composition as a compliance strategy), using AEO 2011-projected shift in passenger car market share as provided by EIA would cause the agencies to understate the cost of achieving compliance through additional technology alone. Therefore, for analyses supporting today's final rule, the agencies developed a new projection of passenger car and light truck sales shares by using NEMS to run scenarios from the AEO 2011 reference case, after first deactivating the above-mentioned sales-volume shifting methodology and holding post-2017 CAFE standards constant at MY 2016 levels. Incorporating these changes reduced the projected passenger car share of the light vehicle market by an average of about 5% during 2017-2025. This case is referred to as the "Unforced Reference Case," and the values are shown below in Table 1-5.

Table 1-4 AEO 2011 Reference Case Volumes

Model Year	Cars	Trucks	Total Vehicles
2017	8,984,200	6,812,000	15,796,100
2018	8,998,200	6,552,200	15,550,400
2019	9,170,900	6,391,300	15,562,200
2020	9,553,600	6,336,200	15,889,800
2021	9,801,100	6,380,000	16,181,100
2022	10,056,600	6,384,600	16,441,200

2023	10,244,500	6,396,500	16,641,000
2024	10,483,400	6,407,700	16,891,100
2025	10,739,600	6,470,200	17,209,800

Table 1-5 AEO 2011 Interim Unforced Reference Case Volumes

Model Year	Cars	Trucks	Total Vehicles
2017	8,440,703	7,365,619	15,806,322
2018	8,376,192	7,200,218	15,576,410
2019	8,464,457	7,114,201	15,578,658
2020	8,725,709	7,170,230	15,895,939
2021	8,911,173	7,277,894	16,189,066
2022	9,123,436	7,316,337	16,439,772
2023	9,344,051	7,311,438	16,655,489
2024	9,580,693	7,353,394	16,934,087
2025	9,836,330	7,414,129	17,250,459

In this 2017 projection, car and light truck sales are expected to get up to 8.4 and 7.4 million units, respectively. While the total level of sales of 15.8 million units is similar to pre-2008 levels, the fraction of car sales in 2017 and beyond is projected to be higher than in the 2000-2007 time frame. Note that EIA's definition of cars and trucks follows that used by NHTSA prior to the MY 2011 CAFE final rule. The MY 2011 CAFE final rule reclassified approximately 1 million 2-wheel drive sport utility vehicles from the truck fleet to the car fleet. EIA's sales projections of cars and trucks for the 2017-2025 model years under the old NHTSA truck definition are shown above in Table 1-4 and Table 1-5.

In addition to a shift towards more car sales, sales of segments within both the car and truck markets have also been changing and are expected to continue to change in the future. Manufacturers are continuing to introduce more crossover models which offer much of the utility of SUVs but use more car-like designs and unibody structures. In order to reflect these changes in fleet makeup, EPA and NHTSA used a custom long range forecast purchased from CSM Worldwide (CSM). CSM[j,k] is a well-known industry analyst that provided the forecast used by the agencies for the 2012-2016 final rule. NHTSA and EPA decided to use the forecast from CSM in the MY 2008 baseline reference fleet for several reasons. One, CSM

[j] CSM World Wide is a paid service provider.

[k] As with any long range forecast, CSM World Wide's forecast out to 2025 has uncertainties since many manufacturers do not have full future product plans out that far.

uses a ground up approach (*e.g.*, looking at the number of plants and capacity for specific engines, transmissions, and vehicles) for their forecast, which the agencies believe is a robust forecasting approach[1]. Two, CSM agreed to allow us to publish their high level data, on which the forecast is based, in the public domain. Three, the CSM forecast covered all the timeframe of greatest relevance to this analysis (2017-2025 model years). Four, it provided projections of vehicle sales both by manufacturer and by market segment. And five, it utilized market segments similar to those used in the EPA emission certification program and fuel economy guide, such that the agencies could include only the vehicle types covered by the final standards. The agencies note that CSM developed the forecast during a period when the United States economy was undergoing significant stress and some automobile manufacturers were experiencing a high degree of financial uncertainty. In the time since CSM developed its forecast ,industry sales and in particular the sales for some individual manufacturers have turned out differently than in the CSM forecast. Because forecasting the market out to MY 2025 has uncertainties, the agencies believe there are benefits from using the CSM forecast for one of the two analyses cases to reflect some level of uncertainty in the final rule analysis. It is feasible that the CSM forecast could represent what might happen in the future.

CSM created a forecast that covered model years 2017-2025. Since the agencies used this forecast to generate the reference fleet (*i.e.*, the fleet expected to be sold absent any increases in the stringency regulations after the 2016 model year), it is important for the forecast not to reflect changes in fleet composition during 2017-2025 attributed to CAFE/ GHG standards. However, CSM assumed that CAFE and GHG standards would continue to increase in stringency after 2016, although CSM did not use specific future standards as quantitative inputs to its model. In its quantitative analysis, CSM used fuel price, industry demand, consumer demand and other economic factors to project the composition of the future fleet. In response to question by the agencies, CSM indicated that their assumption of future standards had a negligible (non-discernible) impact on their forecast since it was not a direct quantitative input to the model such that CSM's forecast would have been essentially the same had CSM assumed no stringency increases after 2016.

The agencies combined the CSM forecast with data from other sources to create the reference fleet projections. This process is discussed in sections that follow.

[1] There are other forecasting groups that do similar projections and meet all these criteria. LMC Automotive (formerly JD Power Forecasting) is another, and this was used for the alternate reference case projection as described below.

1.3.2.2 How do the agencies develop the reference vehicle fleet?

The process of producing the 2017-2025 reference fleet involved combining the baseline fleet with the projection data described above. This was a complex multistep procedure, which is described in this section.

1.3.2.3 How was the 2008 baseline data merged with the CSM data?

For the NPRM, EPA and NHTSA employed the same methodology as in the 2012-16 rule for mapping certification vehicles to CSM vehicles; the results were used again for analysis supporting today's final rule. Merging the 2008 baseline data with the 2017-2025 CSM data required a thorough mapping of certification vehicles to CSM vehicles by individual make and model. One challenge that the agencies faced when determining a reference case fleet was that the sales data projected by CSM had different market segmentation than the data contained in EPA's database. In order to create a common segmentation between the two databases, the agencies performed a side-by-side comparison of each vehicle model in both datasets, and created an additional "CSM segment" modifier in the spreadsheet to map the two datasets. The reference fleet sales based on the "CSM segmentation" was then projected.

The baseline data and reference fleet volumes are available to the public. The baseline Excel spreadsheet in the docket is the result of the merged files.[4] The spreadsheet provides specific details on the sources and definitions for the data. The Excel file contains several tabs. They are: "Data", "Data Tech Definitions", "SUM", "SUM Tech Definitions", "Truck Vehicle Type Map", and "Car Vehicle Type Map". "Data" is the tab with the raw data. "Data Tech Definitions" is the tab where each column is defined and its data source named. "SUM" is the tab where the raw data is processed to be used in the OMEGA and Volpe models. The "SUM" tab minus columns A-F and minus the Generic vehicles is the input file for the models. The "Generic" manufacturer (shown in the "SUM" tab) is the sum of all manufacturers and is calculated as a reference, and for data verification purposes. It is used to validate the manufacturers' totals. It also gives an overview of the fleet.

Table 1-6 shows the sum of the models chosen. The number of models is determined by the number of unique segment and vehicle type combinations. These combinations of segment and vehicle type (the vehicle type number is the same as the technology package number) are determined by the technology packages discussed in the EPA RIA. "SUM Tech Definitions" is the tab where the columns of the "SUM" tab are defined. The "Truck Vehicle Type Map" and "Car Vehicle Type Map" map the number of cylinder and valve actuation technology to the "tech package" vehicle type number.

Table 1-6 Models from the SUM Tab Model

Model
Car Like LargeSuv >=V8 Vehicle Type: 13
Car Like LargeSuv V6 Vehicle Type: 16
Car Like LargeSuv V6 Vehicle Type: 12

Car Like LargeSuv V6   Vehicle Type: 9
Car Like LargeSuv I4 and I5   Vehicle Type: 7
Car Like MidSizeSuv V6   Vehicle Type: 8
Car Like MidSizeSuv V6   Vehicle Type: 5
Car Like MidSizeSuv I4   Vehicle Type: 7
Car Like SmallSuv V6   Vehicle Type: 12
Car Like SmallSuv V6   Vehicle Type: 4
Car Like SmallSuv I4   Vehicle Type: 3
LargeAuto >=V8   Vehicle Type: 13
LargeAuto >=V8   Vehicle Type: 10
LargeAuto >=V8   Vehicle Type: 6
LargeAuto V6   Vehicle Type: 12
LargeAuto V6   Vehicle Type: 5
MidSizeAuto >=V8   Vehicle Type: 13
MidSizeAuto >=V8   Vehicle Type: 10
MidSizeAuto >=V8 (7 or >)   Vehicle Type: 6
MidSizeAuto V6   Vehicle Type: 12
MidSizeAuto V6   Vehicle Type: 8
MidSizeAuto V6   Vehicle Type: 5
MidSizeAuto I4   Vehicle Type: 3

In the combined EPA certification and CSM database, all 2008 vehicle models were assumed to continue out to 2025, though their volumes changed in proportion to CSM projections. Also, any new models expected to be introduced within the 2009-2025 timeframe are not included in the data. These volumes are reassigned to the existing models to keep the overall fleet volume the same. All MYs 2017-2025 vehicles are mapped to the existing vehicles by a process of mapping to manufacturer market share and overall segment distribution. The mappings are discussed in the next section. Further discussion of this limitation is discussed below in section 1.3.2.4. The statistics of this fleet will be presented below since further modifications were required to the volumes as the next section describes.

1.3.2.4 How were the CSM forecasts normalized to the AEO forecasts for the 2008-based fleet?

The next step in the agencies' generation of the reference fleet is one of the more complicated steps to explain. Here, the projected CSM forecasts for relative sales of cars and trucks by manufacturer and by market segment was normalized (set equal) to the total sales estimates of the Early Release of the 2011 Annual Energy Outlook (AEO). NHTSA and EPA used projected car and truck volumes for this period from Early AEO 2011. However, the AEO projects sales only at the car and truck level, not at the manufacturer and model-specific level, and the agencies' analysis requires this further level of detail. The CSM data provided year-by-year percentages of cars and trucks sold by each manufacturer as well as the percentages of each vehicle segment. Using these percentages normalized to the AEO-projected volumes then provided the manufacturer-specific market share and model-specific sales for model years 2017-2025 (it is worth clarifying that the agencies are not using the model-specific sales volumes from CSM, only the higher-level volumes by manufacturer and segment). This process is described in greater detail in the following paragraphs.

In order to determine future production volumes, the agencies developed multipliers by manufacturer and vehicle segment that could be applied to MY 2008 volumes. The process for developing the multipliers is complicated, but is easiest to explain as a three-step process, though the first step is combined with both the second and third step, so only one multiplier per manufacturer and vehicle segment is developed.

The three steps are:

1. Adjust total car and truck sales to match AEO projections.
2. Adjust car sales to match CSM market share projections for each manufacturer and car segment.
3. Adjust truck sales to match CSM market share projections for each manufacturer and truck segment.

The first step is the adjustment of total car and truck sales in 2008 to match AEO projections of total car and truck sales in 2017-2025. The volumes for all of the trucks in 2008 were added up (TruckSum2008), and so were the volumes of all the cars (CarSum2008). A multiplier was developed to scale the volumes in 2008 to the AEO projections. The example equation below shows the general form of how to calculate a car or truck multiplier. The AEO projections are shown above in Table 1-4.

Example Equation **:**

TruckMultiplier(Year X) = AEOProjectionforTrucks(Year X) / TruckSum2008

CarMultiplier(Year X) = AEOProjectionforCars(Year X) / CarSum2008

Where: Year X is the model year of the multiplier.

The AEO projection is different for each model year. Therefore, the multipliers are different for each model year. The multipliers can be applied to each 2008 vehicle as a first adjustment, but multipliers based solely on AEO have limited value since those multipliers can only give an adjustment that will give the correct total numbers of cars and trucks without the correct market share or vehicle mix. A correction factor based on the CSM data, which does contain market share and vehicle segment mix, is therefore necessary, so combining the AEO multiplier with CSM multipliers (one per manufacturer, segment, and model year) will give the best multipliers.

There were several steps in developing an adjustment for Cars based on the CSM data. CSM provided data on the market share and vehicle segment distribution. The first step in determining the adjustment for Cars was to total the number of Cars in each vehicle segment by manufacturer in MY 2008. A total for all manufacturers in each segment was also calculated. The next step was to multiply the volume of each segment for each manufacturer by the CSM market share. The AEO multiplier was also applied at this time. This gave projected volumes with AEO total volumes and market share correction for Cars. This is shown in the "Adjusted for 2017AEO and Manufacturer Market Share" column of Table 1-7.

The next step is to adjust the sales volumes for CSM vehicle segment distribution. The process for adjusting for vehicle segment is more complicated than a simple one step multiplication. In order to keep manufacturers' volumes constant and still have the correct vehicle segment distribution, vehicles need to move from segment to segment while maintaining constant manufacturers' totals. Six rules and one assumption were applied to accomplish the shift. The assumption (based on the shift in vehicle sales in 2008 and 2009) is that people are moving to smaller vehicles in the rulemaking time frame independently of regulatory requirements. A higher-level (less detailed) example of this procedure is provided in Section II of the preamble.

Vehicles from CSM's "Luxury Car," "Specialty Car," and "Other Car" segments, if reduced, will be equally distributed to the remaining four categories ("Full-Size Car," "Mid-Size Car," "Small Car," "Mini Car"). If these sales increased, they were taken from the remaining four categories so that the relative sales in these four categories remained constant.

Vehicles from CSM's "Luxury Car," "Specialty Car," and "Other Car" segments, if increased will take equally from the remaining categories ("Full-Size Car," "Mid-Size Car," "Small Car," "Mini Car").

All manufacturers have the same multiplier for a given segment shift based on moving all vehicles in that segment to achieve the CSM distribution. Table 1-7 shows how the 2017 vehicles moved and the multipliers that were created for each adjustment. This does not mean that new vehicle segments will be added (except for Generic Mini Car described in the next step) to manufacturers that do not produce them. Vehicles within each manufacturer will be shifted as close to the distribution as possible given the other rules. Table 1-8 has the percentages of Cars per CSM segment. These percentages are multiplied by the total number of vehicles in a given year to get the total sales in the segment. Table 1-7 shows the totals for 2017 in the "2017 AEO-CSM Sales Goal" column.

When "Full-Size Car," "Mid-Size Car," "Small Car" are processed, if vehicles need to move in or out of the segment, they will move into or out of the next smaller segment. So, if Mid-Size Cars are being processed they can only move to or be taken from Small Cars. Note: In order to accomplish this, a "Generic Mini Car" segment was added to manufacturers who did not have a Mini (type) Car in production in 2008, but needed to shift down vehicles from the Small Car segment.

The data must be processed in the following order: "Luxury Car," "Specialty Car," "Other Car," "Full-Size Car," "Mid-Size Car," "Small Car." The "Mini Car" does not need to be processed separately. By using this order, it works out that vehicles will always move toward the correct distribution. There are two exceptions, BMW and Porsche only have

"Luxury Car," "Specialty Car," and "Other Car" vehicles, so their volumes were not changed or shifted since these rules did not apply to them.

When an individual manufacturer multiplier is applied for a segment, the vehicles move to or from the appropriate segments as specified in the previous rules and as shown in Table 1-7.

Table 1-7 2017 Model Year Volume Shift*

CSM Segment	2008 MY Sales	Adjusted for 2017 AEO and Manufacturer Market Share	Luxury, Specialty, Other Adjustment	Full Size Adjustment	Midsize Adjustment	Small Car Adjustment	2017 AEO-CSM Sales Goal
All Full-Size Car	829,896	830,832	818,226	347,034	347,034	347,034	347,034
All Luxury Car	1,048,341	1,408,104	1,423,691	1,423,691	1,423,691	1,423,691	1,423,691
All Mid-Size Car	2,103,108	2,500,723	2,475,267	2,946,459	2,431,715	2,431,715	2,431,715
All Mini Car	617,902	868,339	851,234	851,234	851,234	1,439,985	1,439,985
All Small Car	1,912,736	2,548,393	2,513,350	2,513,350	3,028,094	2,439,343	2,439,343
All Specialty Car	469,324	627,425	702,048	702,048	702,048	702,048	702,048
All Others	0	0	0	0	0	0	0
Number Vehicles that shift and Where							
All Full-Size Car			(12,606)	(471,192)	0	0	
All Luxury Car			15,587	0	0	0	
All Mid-Size Car			(25,456)	471,192	(514,744)	0	
All Mini Car			(17,105)	0	0	588,751	
All Small Car			(35,043)	0	514,744	(588,751)	
All Specialty Car			74,623	0	0	0	
All Others			0	0	0	0	
Individual Manufacturer Multiplier							
All Full-Size Car				0.42			
All Luxury Car			0.973				
All Mid-Size Car					0.97		
All Mini Car						1.55	
All Small Car						0.96	
All Specialty Car			0.963				
All Others			1				

Table 1-8 CSM – Percent of Cars per Segment*

CSM Segment	2017	2018	2019	2020	2021	2022	2023	2024	2025
Compact Car	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Full-Size Car	3.95%	3.56%	3.35%	4.10%	3.59%	3.03%	2.97%	2.46%	2.46%
Luxury Car	16.70%	16.87%	17.14%	17.23%	17.05%	17.02%	17.10%	17.40%	17.40%
Mid-Size Car	27.68%	27.77%	27.47%	26.94%	27.18%	27.82%	28.51%	28.11%	28.11%
Mini Car	15.33%	15.46%	15.45%	15.46%	15.59%	15.67%	15.47%	15.23%	15.23%
Small Car	27.77%	27.57%	27.74%	27.99%	28.29%	28.43%	28.18%	28.49%	28.49%
Specialty Car	8.56%	8.76%	8.84%	8.27%	8.29%	8.03%	7.77%	8.31%	8.31%
Others	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Mathematically, an individual manufacturer multiplier is calculated by making the segment the goal and dividing by the previous total for the segment (shown in Table 1-8). If the number is greater than 1, the vehicles are entering the segment, and if the number is less than 1, the vehicles are leaving the segment. So, for example, if Luxury Cars have an adjustment of 1.5, then for a specific manufacturer who has Luxury Cars, a multiplier of 1.5 is applied to its luxury car volume, and the total number of vehicles that shifted into the Luxury segment is subtracted from the remaining segments to maintain that company's market share. On the other hand, if Large Cars have an adjustment of 0.7, then for a specific manufacturer who has Large Cars, a multiplier of 0.7 is applied to its Large Cars, and the total number of vehicles leaving that segment is transferred into that manufacturer's Mid-Size Cars.

After the vehicle volumes are shifted using the above rules, a total for each manufacturer and vehicle segment is maintained. The total for each manufacturer segment for a specific model year (*e.g.*, 2017 General Motors Luxury Cars) divided by the MY 2008 total for that manufacturer segment (*e.g.*, 2008 General Motors Luxury Cars) is the new multiplier used to determine the future vehicle volume for each vehicle model. This is done by taking the multiplier (which is for a specific manufacturer and segment) times the MY 2008 volume for the specific vehicle model (*e.g.*, 2008 General Motors Luxury Car Cadillac CTS). This process is repeated for each model year (2017-2025).

The method used to adjust CSM Trucks to the AEO market share was different than the method used for Cars. The process for Cars is different than Trucks because it is not possible to predict how vehicles would shift between segments based on current market trends. This is because of the added utility of some trucks that makes their sales more insensitive to factors like fuel price. Again, CSM provided data on the market share and vehicle segment distribution. The process for having the fleet match CSM's market share and vehicle segment distribution was iterative.

The following totals were determined:

- The total number of trucks for each manufacturer in 2008 model year.
- The total number of trucks in each truck segment in 2008 model year.
- The total number of truck in each segment for each manufacturer in 2008 model year.
- The total number of trucks for each manufacturer in a specific future model year based on the AEO and CSM data. This is the goal for market share.
- The total number of trucks in each truck segment in a specific future model year based on the AEO and CSM data. This is the goal for vehicle segment distribution. Table 1-9 has the percentages of Trucks per CSM segment.

Table 1-9 CSM – Percent of Trucks per Segment

CSM Segment	2017	2018	2019	2020	2021	2022	2023	2024	2025
Full-Size CUV	5.9%	6.3%	6.8%	7.5%	8.3%	8.8%	9.5%	9.2%	9.1%
Full-Size Pickup	16.8%	16.5%	15.9%	16.1%	15.4%	15.1%	14.3%	13.8%	13.5%
Full-Size SUV	1.9%	1.5%	1.3%	1.0%	0.9%	0.8%	0.5%	0.5%	0.6%
Full-Size Van	1.2%	1.2%	1.1%	1.4%	1.3%	1.3%	1.3%	1.2%	1.2%
Mid-Size CUV	18.0%	17.4%	17.6%	17.2%	16.9%	16.8%	16.8%	17.0%	17.0%
Mid-Size MAV	4.5%	4.6%	4.9%	5.4%	5.9%	6.2%	6.5%	7.1%	7.4%
Mid-Size Pickup	6.1%	6.1%	6.1%	5.6%	5.7%	5.7%	5.8%	5.9%	5.8%
Mid-Size SUV	4.1%	4.8%	4.8%	4.5%	4.7%	4.8%	4.8%	4.6%	4.6%
Mid-Size Van	11.6%	11.9%	11.9%	11.7%	11.6%	11.6%	11.6%	11.3%	11.3%
Small CUV	26.0%	25.9%	25.7%	25.6%	25.1%	24.9%	24.7%	25.3%	25.3%
Small MAV	2.5%	2.6%	2.8%	2.9%	3.0%	3.1%	3.1%	3.2%	3.2%
Small SUV	1.3%	1.2%	1.1%	1.2%	1.1%	1.1%	1.1%	1.0%	1.0%

To start, the agencies created two different types of tables. One table had each manufacturer with its total sales for 2008 (similar to Table 1-11). This table will have the goal for each manufacturer, and a column added for each iteration with the current total. The second table has a truck segment total by manufacturer. The second table starts out with a "Generic" manufacturer (Table 1-11) which is the table where the goal resides. Each manufacturer (BMW for example is shown in Table 1-12) is then listed below the "Generic" manufacturer. With each iteration, a new total is added for each segment that is calculated and added to the table. This is not shown in the tables below. The agencies then engaged in a process of first adjusting the numbers in the tables to the goal for market share distribution. This was followed by adjusting to the goal for vehicle segment distribution. Each time an adjustment was done a new column was added. An adjustment was done by creating a multiplier (either segment distribution-based or manufacturer distribution-based) and applying it to each vehicle segment total in the current iteration. A manufacturer-based multiplier is calculated by taking the goal total for a manufacturer and dividing by the current total (starting with 2008 model year volumes) for a manufacturer. A segment distribution-based multiplier is calculated by taking the goal distribution volumes in the Generic manufacturer set and dividing them by the current volume. Table 1-10, Table 1-11, and Table 1-12 below illustrates two iterations using BMW as an example.

Table 1-10 Manufacturer Truck Totals

	2008 Model Year Sales	Manufacturer Distribution 2017 Volume Goal	Multiplier for Iteration 1
BMW	61,324	138.053	138,053/61324=2.25

Table 1-11 Segment Specific Truck Totals for All Manufacturers

Manufacturer	CSM Segment	2008 Model Year Sales	Segment Distribution 2017 Volume Goal	Multipliers
Generic**	Full-Size Pickup	1,332,335	1,240,844	0.931
Generic	Mid-Size Pickup	452,013	452,017	1.000
Generic	Full-Size Van	33,384	85,381	2.558
Generic	Mid-Size Van	719,529	855,022	1.188
Generic	Mid-Size MAV	110,353	331,829	3.007
Generic	Small MAV	231,265	186,637	0.807
Generic	Full-Size SUV	559,160	138,821	0.248
Generic	Mid-Size SUV	436,080	305,382	0.700
Generic	Small SUV	196,424	94,657	0.482
Generic	Full-Size CUV	264,717	433,683	1.638
Generic	Mid-Size CUV	923,165	1,327,905	1.438
Generic	Small CUV	1,612,029	1,913,439	1.187

** Generic means all manufacturers.

Table 1-12 Segment Specific Truck Totals for BMW

Manufacturer	CSM Segment	2008 Model Year Sales	Iteration 1 Adjust for Market Share	Iteration 2 Adjust for Segment Distribution
BMW	Full-Size Pickup			
BMW	Mid-Size Pickup			
BMW	Full-Size Van			
BMW	Mid-Size Van			
BMW	Mid-Size MAV	3,882	2.25*3,882=8,739	2.85*8,739=24,907
BMW	Small MAV			
BMW	Full-Size SUV			
BMW	Mid-Size SUV			
BMW	Small SUV			
BMW	Full-Size CUV			
BMW	Mid-Size CUV	36,409	2.25*36,409=81,964	1.1*81,964=90,134
BMW	Small CUV	21,033	2.25*21,033=47,350	1..02*47,350=48,306
Total BMW Vehicles		61,324	138,053	163,347

Using this process, the numbers will get closer to the goal of matching CSM's market share for each manufacturer and distribution for each vehicle segment after each of the iterations. The iterative process is carried out until the totals nearly match the goals.

After 19 iterations, all numbers were within 0.01% of CSM's distributions. The calculation iterations could have been stopped sooner, but they were continued to observe how the numbers would converge.

After the market share and segment distribution were complete, the totals need to be used to create multipliers that could be applied to the original individual 2008 model year vehicle volumes (each unique manufacture models volume). The total for each manufacturer segment divided by the 2008 model year total for each manufacturer segment gives a multiplier that can be applied to each vehicle based on its manufacturer and segment.

The above process is done for each model year needed (2017-2025). The multipliers are then applied to each vehicle in 2008 model year, which gives a volume for each vehicle in 2017 through 2025 model year.

1.3.3 What are the sales volumes and characteristics of the MY 2008 based reference fleet?

Table 1-13 and Table 1-15 below contain the sales volumes that result from the process above for MY 2008 and 2017-2020. Table 1-14 and Table 1-16 below contain the sales volumes that result from the process above for MY 2021-2025.

Table 1-13 Vehicle Segment Volumes[a]

Reference Class Segment	Actual and Projected Sales Volume				
	2008	2017	2018	2019	2020

LargeAuto	562,240	376,107	356,768	353,609	394,864
MidSizeAuto	3,098,927	3,311,268	3,290,408	3,303,621	3,381,785
CompactAuto	1,979,461	2,347,980	2,325,393	2,369,301	2,448,021
SubCmpctAuto	1,365,833	2,458,222	2,454,112	2,489,208	2,553,350
LargePickup	1,582,226	1,514,619	1,443,766	1,383,190	1,386,195
SmallPickup	177,497	156,227	157,932	160,752	146,029
LargeSUV	2,783,949	3,194,489	3,150,101	3,177,868	3,203,244
MidSizeSUV	1,263,360	1,358,755	1,309,212	1,267,394	1,285,822
SmallSUV	285,355	148,251	149,933	154,675	162,677
MiniVan	642,055	754,562	739,551	717,065	714,323
CargoVan	110,858	185,841	199,234	201,974	219,628

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table 1-14 Vehicle Segment Volumes[a]

Reference Class Segment	Projected Sales Volume				
	2021	2022	2023	2024	2025
LargeAuto	380,192	358,295	362,672	356,173	368,843
MidSizeAuto	3,442,116	3,548,263	3,692,533	3,751,496	3,814,941
CompactAuto	2,520,977	2,592,199	2,632,926	2,744,634	2,843,069
SubCmpctAuto	2,626,364	2,687,167	2,721,102	2,796,061	2,878,288
LargePickup	1,368,301	1,349,421	1,301,293	1,271,751	1,260,389
SmallPickup	150,123	147,138	151,315	154,627	154,838
LargeSUV	3,312,914	3,362,608	3,412,753	3,475,873	3,520,992
MidSizeSUV	1,281,240	1,283,244	1,268,288	1,292,662	1,305,362
SmallSUV	167,223	169,643	170,239	173,191	175,713
MiniVan	729,078	738,982	740,785	720,720	726,256
CargoVan	210,539	202,812	201,585	196,900	201,768

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table 1-15 2011+ NHTSA Car and Truck Definition Based Volumes

Vehicle Type	Actual and Projected Sales Volume				
	2008	2017	2018	2019	2020
Trucks	5,621,193	5,818,655	5,671,046	5,582,962	5,604,377
Cars	8,230,568	9,987,667	9,905,364	9,995,696	10,291,562
Cars and Trucks	13,851,761	15,806,322	15,576,410	15,578,658	15,895,939

Table 1-16 2011+ NHTSA Car and Truck Definition Based Volumes

Vehicle Type	Projected Sales Volume				
	2021	2022	2023	2024	2025

Trucks	5,683,902	5,703,996	5,687,486	5,675,949	5,708,899
Cars	10,505,165	10,735,777	10,968,003	11,258,138	11,541,560
Cars and Trucks	16,189,066	16,439,772	16,655,489	16,934,087	17,250,459

Table 1-17 and Table 1-18 below contain the sales volumes by manufacturer and vehicle type for MY 2008 and 2017-2025.

Table 1-17 NHTSA Car and Truck Definition Manufacturer Volumes

Manufacturers	Vehicle Type	2008 Baseline Sales	2017 Projected Volume	2018 Projected Volume	2019 Projected Volume	2020 Projected Volume
All	Both	13,851,761	15,806,322	15,576,410	15,578,658	15,895,939
All	Cars	8,230,568	9,987,667	9,905,364	9,995,696	10,291,562
All	Trucks	5,621,193	5,818,655	5,671,046	5,582,962	5,604,377
Aston Martin	Cars	1,370	1,035	1,051	1,072	1,034
Aston Martin	Trucks	-	-	-	-	-
BMW	Cars	291,796	313,022	322,939	346,075	357,942
BMW	Trucks	61,324	138,053	131,942	131,373	128,339
Chrysler/Fiat	Cars	703,158	418,763	397,538	391,689	415,319
Chrysler/Fiat	Trucks	956,792	409,702	387,858	366,447	360,677
Daimler	Cars	208,195	284,847	276,409	281,425	290,989
Daimler	Trucks	79,135	86,913	83,651	88,188	92,919
Ferrari	Cars	1,450	6,676	6,700	6,794	6,916
Ferrari	Trucks	-	-	-	-	-
Ford	Cars	956,699	1,299,899	1,311,467	1,332,039	1,378,789
Ford	Trucks	814,194	763,549	748,829	717,773	717,037
Geely/Volvo	Cars	32,748	41,887	42,187	43,125	42,615
Geely/Volvo	Trucks	65,649	88,234	89,394	91,575	93,003
GM	Cars	1,507,797	1,362,761	1,438,355	1,505,025	1,530,755
GM	Trucks	1,587,391	1,462,204	1,474,076	1,493,511	1,544,983
HONDA	Cars	1,006,639	1,154,600	1,138,087	1,144,639	1,163,666
HONDA	Trucks	505,140	596,481	544,619	527,535	525,089
HYUNDAI	Cars	337,869	592,027	578,373	582,971	598,283
HYUNDAI	Trucks	53,158	152,885	151,461	155,642	154,173
Kia	Cars	221,980	322,044	312,370	314,879	323,676
Kia	Trucks	59,472	98,702	98,280	100,679	96,535
Lotus	Cars	252	240	243	250	266
Lotus	Trucks	-	-	-	-	-
Mazda	Cars	246,661	253,540	262,512	266,951	270,078

Mazda	Trucks	55,885	51,788	57,535	57,494	58,154
Mitsubishi	Cars	85,358	65,099	63,671	63,826	65,080
Mitsubishi	Trucks	15,371	37,632	36,300	35,454	35,215
Nissan	Cars	717,869	870,797	849,678	854,400	882,791
Nissan	Trucks	305,546	444,938	412,383	398,559	397,869
PORSCHE	Cars	18,909	35,093	35,444	36,116	35,963
PORSCHE	Trucks	18,797	13,233	12,001	11,469	11,141
Spyker/Saab	Cars	21,706	20,024	20,007	20,144	21,069
Spyker/Saab	Trucks	4,250	2,871	3,596	3,826	3,509
Subaru	Cars	116,035	224,112	216,598	217,095	223,466
Subaru	Trucks	82,546	78,242	75,152	72,832	72,458
Suzuki	Cars	79,339	90,708	89,932	90,568	93,548
Suzuki	Trucks	35,319	22,109	21,385	20,692	20,675
Tata/JLR	Cars	9,596	55,881	56,222	57,267	58,182
Tata/JLR	Trucks	55,584	57,579	56,606	57,854	56,213
Tesla	Cars	800	27,986	28,435	28,990	27,965
Tesla	Trucks	-	-	-	-	-
Toyota	Cars	1,260,364	1,849,196	1,834,181	1,836,306	1,883,734
Toyota	Trucks	951,136	1,330,511	1,223,415	1,142,104	1,154,304
Volkswagen	Cars	291,483	551,638	540,036	537,114	554,822
Volkswagen	Trucks	26,999	128,819	145,491	146,891	146,700

Table 1-18 NHTSA Car and Truck Definition Manufacturer Volumes

Manufacturers	Vehicle Type	2021 Projected Volume	2022 Projected Volume	2023 Projected Volume	2024 Projected Volume	2025 Projected Volume
All	Both	16,189,066	16,439,772	16,655,489	16,934,087	17,250,459
All	Cars	10,505,165	10,735,777	10,968,003	11,258,138	11,541,560
All	Trucks	5,683,902	5,703,996	5,687,486	5,675,949	5,708,899
Aston Martin	Cars	1,058	1,049	1,041	1,141	1,182
Aston Martin	Trucks	-	-	-	-	-
BMW	Cars	359,098	360,034	360,561	388,193	405,256
BMW	Trucks	128,724	128,899	127,521	146,525	145,409
Chrysler/Fiat	Cars	421,013	424,173	423,882	426,017	436,479
Chrysler/Fiat	Trucks	348,613	363,008	361,064	344,962	331,762
Daimler	Cars	300,378	304,738	312,507	332,337	340,719
Daimler	Trucks	99,449	100,935	105,315	107,084	101,067
Ferrari	Cars	7,059	7,138	7,227	7,441	7,658
Ferrari	Trucks	-	-	-	-	-

Ford	Cars	1,401,617	1,415,221	1,474,797	1,503,670	1,540,109
Ford	Trucks	714,181	714,266	700,005	688,854	684,476
Geely/Volvo	Cars	41,768	41,686	42,031	42,461	42,588
Geely/Volvo	Trucks	92,726	92,512	96,840	99,181	101,107
GM	Cars	1,530,020	1,507,653	1,496,819	1,493,597	1,524,008
GM	Trucks	1,564,277	1,578,556	1,606,495	1,636,805	1,673,936
HONDA	Cars	1,198,880	1,237,504	1,265,564	1,307,851	1,340,321
HONDA	Trucks	535,916	539,235	536,898	536,994	557,697
HYUNDAI	Cars	613,355	627,964	634,308	657,710	677,250
HYUNDAI	Trucks	156,466	157,493	161,189	166,092	168,136
Kia	Cars	331,319	339,102	342,746	351,882	362,783
Kia	Trucks	95,432	94,694	95,688	96,119	97,653
Lotus	Cars	278	290	299	308	316
Lotus	Trucks	-	-	-	-	-
Mazda	Cars	274,740	281,150	296,910	300,614	306,804
Mazda	Trucks	59,227	60,307	61,966	61,971	61,368
Mitsubishi	Cars	65,851	67,261	67,680	70,728	73,305
Mitsubishi	Trucks	35,309	35,227	35,469	36,001	36,387
Nissan	Cars	912,629	937,447	954,340	982,771	1,014,775
Nissan	Trucks	408,029	411,883	417,121	422,217	426,454
PORSCHE	Cars	36,475	36,607	36,993	39,504	40,696
PORSCHE	Trucks	11,242	11,385	11,370	11,409	11,219
Spyker/Saab	Cars	21,294	21,709	22,410	22,800	23,130
Spyker/Saab	Trucks	3,560	3,461	3,435	3,426	3,475
Subaru	Cars	230,780	238,613	241,612	248,283	256,970
Subaru	Trucks	72,773	72,736	73,022	74,142	74,722
Suzuki	Cars	95,725	97,599	99,263	100,447	103,154
Suzuki	Trucks	20,767	20,734	20,803	21,162	21,374
Tata/JLR	Cars	58,677	59,349	60,639	63,728	65,418
Tata/JLR	Trucks	58,153	58,590	58,865	57,981	56,805
Tesla	Cars	28,623	28,369	28,150	30,862	31,974
Tesla	Trucks	-	-	-	-	-
Toyota	Cars	1,903,706	1,986,077	2,036,992	2,080,528	2,108,053
Toyota	Trucks	1,215,539	1,235,052	1,224,980	1,208,013	1,210,016
Volkswagen	Cars	585,607	593,314	596,749	605,336	630,163
Volkswagen	Trucks	148,734	146,750	153,927	156,939	154,284

Table 1-19 also shows how the change in fleet make-up may affect the footprint distributions over time. The resulting data indicate that footprint will not change significantly between 2008 and 2025. There will be an increase in the number of cars sold, which will cause the average footprints for cars and trucks combined to be slightly smaller (about 2%).

This is the result of AEO projecting an increased number of cars, and CSM predicting that most of that increase will be in the subcompact segment. Again, we note that in order to ensure that our baseline inputs were not influenced by the final regulations, agencies re-ran AEO to hold standards constant after 2016 (the reader will remember from the text above that CSM had indicated that its projections were not sensitive to assumptions about new standards).

Table 1-19 Production Weighted Foot Print Mean

Model Year	Average Footprint of all Vehicles	Average Footprint Cars	Average Footprint Trucks
2008	48.8	45.2	53.9
2017	48.0	44.6	53.8
2018	47.9	44.6	53.7
2019	47.8	44.6	53.6
2020	47.8	44.6	53.7
2021	47.8	44.6	53.6
2022	47.7	44.6	53.6
2023	47.7	44.6	53.5
2024	47.5	44.6	53.3
2025	47.5	44.6	53.3

Table 1-20 below shows the changes in engine cylinders over the model years. The current assumptions show that engines will be downsized over the model years to which these final rules apply. This shift is a projected consequence of the expected changes in class and segment mix as predicted by AEO and CSM, and does not represent engine downsizing attributable to the 2012-2016 light-duty CAFE and GHG standards.

Table 1-20 Percentages of 4, 6, 8 Cylinder Engines by Model Year

	Trucks			Cars		
Model Year	**4 Cylinders**	**6 Cylinders**	**8 Cylinders**	**4 Cylinders**	**6 Cylinders**	**8 Cylinders**
2008	10.3%	56.4%	33.3%	56.9%	37.8%	5.3%
2017	10.9%	63.7%	25.4%	60.6%	34.5%	5.0%
2018	10.6%	64.5%	24.8%	60.7%	34.4%	5.0%
2019	10.4%	65.5%	24.1%	60.7%	34.3%	5.0%
2020	10.3%	65.6%	24.1%	60.3%	34.7%	5.0%
2021	10.3%	66.3%	23.4%	60.6%	34.4%	4.9%
2022	10.3%	66.7%	23.0%	61.1%	34.2%	4.8%

2023	10.3%	67.7%	22.0%	60.9%	34.3%	4.8%
2024	10.5%	68.1%	21.4%	61.0%	34.1%	4.8%
2025	10.5%	68.2%	21.3%	61.1%	34.0%	4.8%

As discussed above, the agencies also developed a second market forecast using updated data. The following section describes those efforts and their results.

1.4 The 2010 MY Based Fleet

The 2010 MY based fleet is similar to the 2008 MY based fleet in that it was created with similar types of information. The 2010 MY based fleet uses interim AEO 2012 total car and truck volumes, a long range forecast from LMC Automotive (formerly J.D. Powers Forecasting) used for manufacturer market share and product mix, and 2010 CAFE certification data for 2010 model volumes and technology. The 2008 MY based fleet, in contrast, uses interim AEO 2011, a long range forecast from CSM World Wide, and 2008 CAFE certification data. The remainder of section 1.4 describes the 2010 based fleet projection and how it was created.

1.4.1 On what data is the MY 2010 baseline vehicle fleet based?

Similar to the 2008 baseline, most of the information about the vehicles that make up the 2010 fleet was gathered from EPA's emission certification and fuel economy database, most of which is available to the public. These data included, by individual vehicle model produced in MY 2010, vehicle production volume, fuel economy rating for CAFE certification, carbon dioxide emissions, fuel type, fuel injection type, EGR, number of engine cylinders, displacement, intake valves per cylinder, exhaust valves per cylinder, variable valve timing, variable valve lift, engine cycle, cylinder deactivation, transmission type, drive (rear-wheel, all-wheel, etc.), hybrid type (if applicable), and aspiration (naturally-aspirated, turbocharged, etc.). In addition to this information about each vehicle model produced in MY 2010, the agencies augmented this description with publicly-available data which includes more complete technology descriptions from Ward's Automotive Group.[m,n] As with the 2008 baseline, the agencies also used Edmunds.com and Motortrend.com[o,p,q] Like the MY 2008 baseline fleet and the baseline vehicle fleet used in the MYs 2012-2016 rulemaking, the MY 2010 baseline vehicle fleet is developed using publicly-available data to the largest extent possible.

[o] Motortrend.com and Edmunds.com: Used as a source for footprint and vehicle weight data.
[p] Motortrend.com and Edmunds.com are free, no-fee internet sites.
[q] A small amount of footprint data from manufacturers' MY 2008 product plans submitted to the agencies was used in the development of the baseline.

The process for creating the 2010 baseline fleet Excel file was streamlined when compared with the past rulemaking. EPA and NHTSA worked together to create the baseline using 2010 CAFE certification data from EPA's Verify database. EPA contracted LMC Automotive (formerly JD Power Forecasting) to produce an up to date long range forecast of volumes for the future fleet. Using information sources discussed below, NHTSA identified technology and footprint information for every vehicle model in the 2010 CAFE certification data. EPA used the forecast from LMC Automotive to project the future fleet's volume projections (a detailed discussion of the method used to project the future fleet volumes is in 1.4.2.1 of this chapter.)

Both agencies used the previously mentioned data to populate input files for the agencies' respective modeling systems. The structure of the market forecast input file used for DOT's CAFE Compliance and Effects Modeling System (a.k.a. "the CAFE model") is described in the model documentation.[5] To help readers who wish to directly examine the baseline fleet file for EPA's OMEGA model, and to provide some idea of its contents for those readers who do not, Table 1-21 shows the columns of the complete fleet file, which includes the MY 2008 baseline data that was compiled. Each column has its name, definition (description) and source. Most elements shown in Table 1-21 also appear in the market forecast input file for DOT's modeling system, which accommodates some additional data elements discussed in the model documentation.

Table 1-21 Data, Definitions, and Sources

Data Item	Definition	Data Type	Wards Engine Acronyms	Where The Data is From
Index	Index Used to link EPA and NHTSA baselines	Number	NA	Created
Manufacturer	Common name of company that manufactured vehicle. May include more name plates than Cert Manufacturer Name.	Name (Ex.Chrysler)	NA	Certification data
CERT Manufacturer Name	Certification name of company that manufactured vehicle	Name (Ex.Chrysler)	NA	Certification data
Name Plate	Name of Division	Name (Ex. Dodge)	NA	Certification data
Model	Name of Vehicle	Name (Ex.Viper)	NA	Certification data
Reg Class	EPA Fuel Economy Class Name	EPA Class Name (Ex. SUBCOMPACT CARS)	NA	Certification data
Our Class	If a car's Footprint<43 then "SubCmpctAuto" If a car's 43<=Footprint<46 then "CompactAuto" If a car's 46<=Footprint<53 then "MidSizeAuto" If a car's Footprint >=53 then "LargeAuto" If a S.U.V.'s Footprint < 43 then "SmallSuv" If a S.U.V.'s 43<=Footprint<46 then "MidSizeSuv" If a S.U.V's Footprint >=46 then "LargeSuv" If a Truck's Footprint < 50 then "SmallPickup" If a Truck's Footprint>=50 then "LargPickup" If a Van's Structure is Ladder then "CargoVan" If a Van's Structure is Unibody then "Minivan"	Name(Ex. SmallSuv)	NA	Derived From Certification data and Footprint

NEW SEGMENT	LMC Automotive (formerly J. D. Powers) new segmentation for the vehicle.	Name (Ex. Compact Sporty, Large Pickup, etc.)	NA	LMC Automotive
Vehicle Type Number	Vehicle Type Number assigned to a vehicle based on its number of cylinders, valves per cylinder, and valve actuation technology. See Truck Vehicle Type Map and Car Vehicle Type Map sheets for details.	Number	NA	Mapped by EPA staff
Generic Vehicle Index From Sum Page	Number to be used as a cross reference with the Sum Pages.	Number	NA	NA
Vehicle Index From Sum Page	Number to be used as a cross reference with the Sum Pages.	Number	NA	NA
Pre 2011 NHTSA Defined C/T	C= Car, T=Truck. As defined in the certification database.	Letter(C or T)	NA	Certification data
Our Class C/T	C= Car, T=Truck. As defined in the certification database. Not used in calculations.	Letter(C or T)	NA	Created
Traditional Car/Truck	DP=Domestic Passenger Cars, I=Import Passenger Car, LT= Light duty Truck. As defined in the certification database. Not used in calculations.	IP,DP,LT	NA	Certification data
NHTSA Defined New NHTSA Car/Truck	New NHTSA Car Truck value as determined by NHTSA. Used in calculations.	Letter(C or T)	NA	Certification data
Total Production Volume	Total number of vehicles produced for that model.	number(ex.5500)	NA	Certification data
Fuel Econ. (mpg)	EPA Unadjusted Fuel Economy	number(ex.25)	NA	Certification data
CO2	CO2 calculated from MPG. CO2 weighted 1.15 times higher for diesel vehicles.	Number	NA	Certification data
Fuel (G,D,C)	Gas or Diesel or CNG	G,D,C	NA	Certification data
Fuel Type	Gas or Diesel or CNG	Gas or Diesel or CNG	NA	Certification data
Disp (lit.)	Engine Cylinder Displacement Size in Liters	number(ex. 4)	NA	Wards/Certification data
Effective Cyl	Number of Cylinder + 2 if the engine has a turbo or super charger.	number(ex. 6)	NA	Derived From Certification data.
Actual Cylinders	Actual Number of Engine Cylinders	number(ex. 4)	NA	Certification data
Valves Per Cylinder	Number of Valves Per Actual Cylinder	number(ex. 4)	NA	Certification data
Valve Type	Type of valve actuation.	Acronym(Ex. DOHC, SOHC, OHV, E, R)	DOHC, SOHC, OHV, E, R	Wards (Note: Type E is from Cert Data)
Valve Actuation	Type of valve actuation with values compatible with the package file.	DOHC, SOHC, OHV	DOHC, SOHC, OHV	Wards
VVT	Type of valve timing with values compatible with the package file.	VVTC,VVTD, VVTI	VVTC,VVTD, VVTI	Wards
VVLT	Type of valve lift with values compatible with the package file.	VVTLC, VVTLD	VVTLC, VVTLD	Wards

Deac	Cylinder Deactivation with a value that is compatible with the package file.	Deac	CD	Wards
Inline or V Engine	Configuration of the Engine	I or V	I or V	Wards
Fuel injection system	Type of fuel injection.	DI, MPI	DI, SFI, EFI, MPI	Wards
Boost	Type of Boost if any.	Super Charged (Single), Turbo (Single)	TRB,SPR	Wards
Engine Cycle	As Defined by EPA Cert. Definition	Letter Ex. G for Gas)	NA	Wards
Horsepower	Max. Horsepower of the Engine	number(ex. 125)	NA	Wards
Torque	Max. Torque of the Engine	number(ex. 125)	NA	Wards
Cooled EGR	Cooled Exhaust Gas Recirculation	Y or N	NA	Certification data
Trans Type	A=Auto AMT=Automated Manual M=Manual CVT= Continuously Variable Transmission	letter(ex. A)	NA	Certification data
Tran	Type Code with number of Gears	letters and possible a number(ex.A5, ex. CVT)	NA	Certification data
Num of Gears	Number of Gears	number(ex. 4)	NA	Certification data
Structure	Ladder or Unibody	Unibody or Ladder (Ex. Ladder)	NA	Volpe Input File
Drive	Fwd, Rwd, 4wd	Acronym(Ex. Rwd)	NA	Certification data
Drive with AWD	Fwd, Rwd, Awd, 4wd	Acronym(Ex. Awd)	NA	Certification data
Wheelbase	Length of Wheelbase	number(ex. 125)	NA	From Edmonds.com or Motortrend.com,
Track Width (front)	Length of Track Width in inches	number(ex. 45)	NA	From Edmonds.com or Motortrend.com
Track Width (rear)	Length of Track Width in inches	number(ex. 45)	NA	From Edmonds.com or Motortrend.com
Footprint	Car and Large Truck Footprints are normal (Average Track x Wheelbase). Medium and Small Truck footprints are the production weighted average for each vehicle.	Number	NA	From Edmonds.com or Motortrend.com
Threshold FootPrint	Footprint valve that will be set to 41 for values less than 41, Will be set to 56 for car values > 56, and will be set to 66 for truck values >66	Number	NA	Derived from data from Edmunds.com or Motortrend.com
Curb Weight	Curb Weight of the Vehicle	number(ex.4500)	NA	Certification data
ITW	Inertia Test Weight	number(ex.4500)	NA	Certification data
GVWR	Gross Vehicle Weight Rating of the Vehicle	number(ex.4500)	NA	Volpe Input File
Stop-Start/ Hybrid/ Full EV	Type of Electrification if any. Blank = None	EV75,2-Mode-IMA,Power-Split,Stop-Start	NA	Certification data
Towing Capacity (Maximum)	Weight a vehicle is rated to tow.	Number (in Pounds)	NA	Volpe Input File
Engine Oil Viscosity	Ratio between the applied shear stress and the rate of shear, which measures the resistance of flow of the engine oil (as per SAE Glossary of Automotive Terms)	Text (Ex. 0W20; 5W20)	NA	Volpe Input File
Low drag brakes	See Volpe Documentation	See Volpe	NA	Volpe Input File

		Documentation		
Power steering	See Volpe Documentation	See Volpe Documentation	NA	Volpe Input File
Technology Class	For technology application purposes only and should not be confused with vehicle classification for regulatory purposes. Defined by DOT.	Text (Ex. Subcompact, Subcompact Performance, Compact, Compact Performance, Midsize, Midsize Performance, Large, Large Performance, Minivan, Small LT, Midsize LT, Large LT; (LT = SUV/Pickup/Van))	NA	Volpe Input File
Safety Class	See Volpe Documentation	See Volpe Documentation	NA	Volpe Input File
Safety Class Number	See Volpe Documentation	See Volpe Documentation	NA	Volpe Input File
Volume 2010	Projected Production Volume for 2010	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2011	Projected Production Volume for 2011	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2012	Projected Production Volume for 2012	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2013	Projected Production Volume for 2013	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2014	Projected Production Volume for 2014	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2015	Projected Production Volume for 2015	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2016	Projected Production Volume for 2016	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.

Volume 2017	Projected Production Volume for 2017	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2018	Projected Production Volume for 2018	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2019	Projected Production Volume for 2019	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2020	Projected Production Volume for 2020	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2021	Projected Production Volume for 2021	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2022	Projected Production Volume for 2022	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2023	Projected Production Volume for 2023	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2024	Projected Production Volume for 2024	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.
Volume 2025	Projected Production Volume for 2025	Number	NA	Calculated based on MY2010 volume and AEO and LMC adjustment factors.

Table 1-22 displays the engine technologies present in the MY 2010 baseline fleet. Again, the engine technologies for the vehicles manufactured by these manufacturers in MY 2010 were largely obtained from data found on Ward's Auto online.

Table 1-22 2010 Engine Technology Percentages

Manufacturers	Vehicle Type	Turbo Charged	Super Charged	Single Overhead Cam	Dual Over Head Cam	Over Head Cam	Variable Valve Timing Continuous	Variable Valve Timing Discrete	Variable Valve Timing Intake Only	Variable Valve Lift and Timing Continuous	Variable Valve Lift and Timing Discrete	Cylinder Deactivation	Direct Injection
All	Both	3%	0%	22%	68%	10%	41%	26%	39%	6%	2%	4%	9%
All	Cars	4%	0%	18%	78%	4%	11%	26%	48%	6%	2%	3%	9%
All	Trucks	2%	0%	29%	50%	21%	17%	27%	22%	5%	2%	7%	9%
Aston Martin	Cars	0%	0%	0%	100%	0%	0%	0%	38%	0%	0%	0%	0%
Aston Martin	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BMW	Cars	38%	0%	0%	100%	0%	28%	70%	0%	0%	45%	0%	38%
BMW	Trucks	33%	0%	0%	100%	0%	0%	82%	0%	0%	67%	0%	33%
Chrysler/Fiat	Cars	0%	0%	42%	49%	9%	0%	41%	0%	0%	0%	5%	0%
Chrysler/Fiat	Trucks	0%	0%	30%	4%	66%	0%	4%	0%	0%	0%	13%	0%
Daimler	Cars	0%	0%	50%	50%	0%	52%	46%	0%	0%	46%	0%	0%
Daimler	Trucks	8%	1%	24%	76%	0%	24%	69%	0%	0%	76%	0%	8%
Ferrari	Cars	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	90%
Ferrari	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ford	Cars	1%	0%	12%	88%	0%	2%	0%	69%	0%	0%	0%	1%
Ford	Trucks	1%	0%	70%	30%	0%	50%	0%	26%	0%	0%	0%	1%
Geely	Trucks	38%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%
Geely	Cars	25%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%
General Motors	Trucks	0%	0%	0%	45%	55%	0%	42%	0%	0%	0%	4%	37%
General Motors	Cars	0%	0%	0%	75%	25%	0%	73%	1%	0%	0%	3%	31%
Honda	Cars	1%	0%	58%	42%	0%	58%	42%	0%	42%	0%	17%	0%
Honda	Trucks	2%	0%	63%	37%	0%	63%	37%	0%	37%	0%	45%	0%
Hyundai	Cars	3%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Hyundai	Trucks	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Kia	Cars	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Kia	Trucks	0%	0%	0%	100%	0%	0%	0%	73%	0%	0%	0%	0%
Lotus	Cars	0%	16%	0%	100%	0%	0%	100%	0%	23%	0%	0%	0%
Lotus	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mazda	Cars	4%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	2%
Mazda	Trucks	11%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Mitsubishi	Cars	6%	0%	100%	0%	0%	96%	0%	0%	0%	0%	0%	0%
Mitsubishi	Trucks	0%	0%	100%	0%	0%	74%	0%	0%	0%	0%	0%	0%
Nissan	Cars	0%	0%	0%	100%	0%	0%	0%	100%	9%	0%	0%	0%
Nissan	Trucks	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%
Porsche	Cars	16%	0%	0%	100%	0%	0%	0%	100%	100%	0%	0%	83%
Porsche	Trucks	1%	0%	0%	100%	0%	0%	0%	100%	100%	0%	0%	100%
Spyker	Cars	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Spyker	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Subaru	Cars	6%	0%	92%	8%	0%	0%	2%	6%	2%	0%	0%	0%

Subaru	Trucks	0%	0%	87%	13%	0%	0%	13%	0%	13%	0%	0%	0%
Suzuki	Cars	0%	0%	0%	100%	0%	0%	2%	98%	0%	0%	0%	0%
Suzuki	Trucks	0%	0%	0%	100%	0%	0%	50%	50%	0%	0%	0%	0%
Tata	Cars	0%	22%	0%	100%	0%	0%	67%	33%	45%	7%	0%	67%
Tata	Trucks	0%	15%	0%	100%	0%	0%	67%	33%	64%	0%	0%	67%
Tesla	Cars	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tesla	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Toyota	Cars	0%	0%	0%	100%	0%	0%	16%	84%	0%	0%	0%	4%
Toyota	Trucks	0%	0%	0%	100%	0%	0%	62%	38%	0%	0%	0%	0%
Volkswagen	Cars	62%	4%	68%	32%	0%	47%	32%	0%	1%	0%	0%	68%
Volkswagen	Trucks	33%	0%	21%	79%	0%	21%	67%	0%	52%	0%	0%	100%

The data in Table 1-22 indicate that manufacturers had already begun implementing a number of fuel economy/GHG reduction technologies in the baseline (2010) fleet. For example, as in the 2008 baseline fleet, VW stands out as having a significant number of turbocharged direct injection engines. Some of the valve and cam technologies are quite common in the baseline fleet: for example, nearly half the baseline fleet already has dual cam phasing, while Honda and Chrysler have considerable levels of engines with cylinder deactivation. Honda also has already implemented continuously variable valve lift on a majority of their engines. Part of the implication of these technologies already being present in the baseline is that if manufacturers have already implemented them, they are therefore not available in the rulemaking analysis for improving fuel economy and reducing CO_2 emissions further, requiring the agencies to look toward increasing penetration of these and other technologies and increasingly advanced technologies to project continued improvements in stringency over time.

The data in Table 1-23 shows the changes between the 2010 engine technology penetrations and the 2008 engine technology penetrations. Perhaps to increase fuel economy, manufacturers applied considerable additional technology between 2008 and 2010. Volkswagen’s trucks have direct injection increased to 100 percent (although VW’s cars had a 21% decrease). Manufacturers changed variable valve timing, presumably based on engine-specific design considerations. For example, Honda replaced discrete valve timing with continuous valve lift or timing, and Kia added variable valve lift and timing to 90% of its cars and 56% of its trucks.

Table 1-23 The difference (2010-2008) in Engine Technology Percentages

Manufacturer	Vehicle Type	Turbo Charged	Super Charged	Single Overhead Cam	Dual Overhead Cam	Overhead Cam	Variable Valve Timing Continuous	Variable Valve Timing Discrete	Variable Valve Timing Intake Only	Variable Valve Lift and Timing Continuous	Variable Valve Lift and Timing Discrete	Cylinder Deactivation	Direct Injection
All	Both	0%	0%	2%	5%	-7%	33%	4%	9%	6%	-10%	-2%	4%
All	Cars	0%	0%	1%	5%	-5%	2%	2%	13%	6%	-11%	0%	2%
All	Trucks	1%	0%	5%	2%	-8%	11%	8%	-1%	5%	-8%	-4%	6%
Aston Martin	Cars	0%	0%	0%	0%	0%	0%	-100%	38%	-24%	0%	0%	0%
Aston Martin	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
BMW	Cars	5%	-1%	-14%	14%	0%	14%	-16%	0%	0%	32%	0%	5%
BMW	Trucks	28%	0%	0%	0%	0%	0%	-18%	0%	0%	67%	0%	27%
Chrysler/Fiat	Cars	-1%	0%	21%	-23%	1%	0%	-1%	0%	0%	0%	0%	0%
Chrysler/Fiat	Trucks	0%	0%	-9%	0%	9%	0%	0%	0%	0%	0%	9%	0%
Daimler	Cars	-2%	0%	-5%	5%	0%	-20%	42%	-13%	0%	46%	0%	-2%
Daimler	Trucks	-8%	0%	-12%	12%	0%	-11%	52%	-47%	0%	76%	0%	-8%
Ferrari	Cars	0%	0%	0%	0%	0%	0%	0%	0%	-29%	0%	0%	90%
Ferrari	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ford	Cars	1%	-1%	-3%	3%	0%	-2%	0%	22%	0%	0%	0%	1%
Ford	Trucks	1%	0%	5%	-2%	-3%	22%	-1%	17%	0%	0%	0%	1%
Geely/Volvo	Trucks	38%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Geely/Volvo	Cars	-24%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
GM	Trucks	0%	0%	0%	14%	-14%	-5%	25%	-14%	0%	0%	-36%	37%
GM	Cars	-1%	0%	0%	19%	-19%	-29%	42%	0%	0%	0%	-1%	25%
Honda	Cars	1%	0%	1%	-1%	0%	58%	15%	-20%	42%	-100%	6%	0%
Honda	Trucks	-2%	0%	-1%	1%	0%	63%	33%	-28%	37%	-100%	45%	-4%
Hyundai	Cars	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Hyundai	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kia	Cars	0%	0%	0%	0%	0%	0%	0%	90%	0%	0%	0%	0%
Kia	Trucks	0%	0%	0%	0%	0%	0%	0%	56%	0%	0%	0%	0%
Lotus	Cars	0%	-61%	0%	0%	0%	0%	0%	0%	23%	0%	0%	0%
Lotus	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mazda	Cars	-7%	0%	0%	1%	0%	0%	-7%	8%	0%	0%	0%	-9%
Mazda	Trucks	-13%	0%	-1%	1%	0%	0%	-13%	13%	0%	0%	0%	-24%
Mitsubishi	Cars	0%	0%	0%	0%	0%	-4%	0%	0%	0%	0%	0%	0%
Mitsubishi	Trucks	0%	0%	0%	0%	0%	36%	0%	0%	0%	0%	0%	0%
Nissan	Cars	0%	0%	0%	0%	0%	0%	-4%	4%	9%	0%	0%	0%
Nissan	Trucks	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Porsche	Cars	-1%	0%	0%	0%	0%	0%	-100%	100%	100%	0%	0%	66%
Porsche	Trucks	-11%	0%	0%	0%	0%	0%	-100%	100%	100%	-100%	0%	0%
Spyker/Saab	Cars	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Spyker/Saab	Trucks	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Subaru	Cars	-9%	0%	23%	-23%	0%	0%	2%	-25%	2%	-1%	0%	0%
Subaru	Trucks	-3%	0%	17%	-17%	0%	0%	-10%	-7%	13%	-27%	0%	0%
Suzuki	Cars	0%	0%	0%	0%	0%	0%	2%	98%	0%	0%	0%	0%

Suzuki	Trucks	0%	0%	0%	0%	0%	0%	50%	50%	0%	0%	0%	0%
Tata/JLR	Cars	0%	22%	0%	0%	0%	0%	-9%	9%	45%	7%	0%	67%
Tata/JLR	Trucks	0%	-5%	0%	0%	0%	0%	67%	-67%	64%	0%	0%	67%
Tesla	Cars	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tesla	Trucks	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toyota	Cars	0%	0%	0%	0%	0%	0%	-13%	13%	0%	0%	0%	-4%
Toyota	Trucks	0%	0%	0%	0%	0%	0%	1%	-1%	0%	0%	0%	-6%
Volkswagen	Cars	19%	4%	-17%	17%	0%	47%	-16%	0%	1%	-1%	0%	-21%
Volkswagen	Trucks	1%	0%	0%	100%	0%	0%	99%	0%	0%	79%	0%	100%

The section below provides further detail on the conversion of the MY 2010 baseline into the MYs 2017-2025 reference fleet. It also describes more of the data contained in the baseline spreadsheet.

1.4.2 The MY 2010 Based MY 2017-2025 Reference Fleet

The reference fleet aims to reflect the current market conditions and expectations about conditions of the vehicle fleet during the model years to which the agencies' rules apply. Fundamentally, constructing this fleet involved projecting the MY 2010 baseline fleet into the MYs 2017-2025 model years. It also included the assumption that none of the vehicle models had changes during this period. Projecting this future fleet is a process that is necessarily uncertain. As with the MY 2008-based MY 2017-2025 reference fleet, NHTSA and EPA relied on many sources of reputable information to make these projections.

1.4.2.1 On what data is the reference vehicle fleet based (using the MY2010 baseline)?

EPA and NHTSA have based the projection of total car and light truck sales on the most recent projections available made by the Energy Information Administration (EIA). EIA's Annual Energy Outlook (AEO) projects future energy production, consumption and prices.[6] EIA issued an "early release" version of AEO 2012 in January 2012. The complete final version of AEO 2012 was released June 25, 2012, but by that time EPA/NHTSA had already completed analyses supporting the final 2017-2025 standards using the interim data release. Similar to the analyses supporting the MYs 2012-2016 rulemaking and for the 2008 based fleet projection, the agencies have used the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS) to estimate the future relative market shares of passenger cars and light trucks. However, as explained above, NEMS shifts the market toward passenger cars in order to ensure compliance with EISA's requirement that CAFE standards cause the fleet to achieve 35 mpg by 2020. Because we use our market projection as a baseline relative to which we measure the effects of new standards, and we attempt to estimate the industry's ability to comply with new standards without changing product mix (*i.e.*, we analyze the effects of the final rules assuming manufacturers will not change fleet composition as a compliance strategy), using the Interim AEO 2012-projected shift in passenger car market share as provided by EIA would cause the agencies to understate the cost of achieving compliance through additional technology, alone. Therefore, for the current analysis, the agencies developed a new projection of passenger car and light truck sales shares by using NEMS to run scenarios from the Interim AEO 2012 reference case, after first deactivating the above-mentioned sales-volume shifting methodology and holding post-2017 CAFE standards constant at MY 2016 levels. Incorporating these changes reduced the projected passenger car share of the light vehicle market by an average of about 5% during 2017-2025. As with the comparable exercise for the 2008 MY baseline fleet, this case is referred to as the "Unforced Reference Case," and the values are shown below in Table 1-24.

Table 1-24 AEO 2012 Interim Unforced Reference Case Values used in the 2010 Market Fleet Projection

Model Year	Cars	Trucks	Total Vehicles
2017	8,713,800	7,098,300	15,812,100
2018	8,631,900	6,973,500	15,605,400
2019	8,688,600	6,973,500	15,662,100
2020	8,774,500	6,855,700	15,630,200
2021	8,898,400	6,831,700	15,730,100
2022	9,033,900	6,853,300	15,887,200
2023	9,179,600	6,827,600	16,007,200
2024	9,368,800	6,878,200	16,247,000
2025	9,525,700	6,929,100	16,454,800

In 2017, car and light truck sales are projected to be 8.7 and 7.1 million units, respectively (compared to 8.4 and 7.4 million in the 2010 AEO projection). While the total level of sales of 15.8 million units is similar to pre-2008 levels, the fraction of car sales in 2017 and beyond is projected to be higher than in the previous AEO projections.

In addition to a shift towards more car sales, sales of segments within both the car and truck markets have also been changing and are expected to continue to change in the future. The agencies also wanted to use the most updated information on Chrysler projections, as the older NPRM projection conducted by CSM showed Chrysler sales to be very low in 2025. The agencies agree with the Chrysler comments that the NPRM projections are most likely outdated and too low with respect to Chrysler's market share. In order to reflect these changes in fleet makeup, EPA and NHTSA used a custom long range forecast purchased from LMC Automotive (formerly J.D. Powers Forecasting). J.D. Powers is a well-known industry analyst. NHTSA and EPA decided to use the forecast from LMC Automotive (J.D. Powers Forecasting) for MY2010-based market forecast for several reasons. First, Like CSM, LMC Automotive uses a ground up approach (*e.g.*, looking at the number of plants and capacity for specific engines, transmissions, and vehicles) for their forecast, which the agencies believe is a robust forecasting approach. Second, LMC Automotive allows us to publish their entire forecast in the public domain. Third, the LMC Automotive forecast covered all the timeframe of greatest relevance to this analysis (2017-2025 model years). Fourth, it provided projections of vehicle sales both by manufacturer and by market segment. Fifth, it utilized market segments similar to those used in the EPA emission certification program and fuel economy guide, such that the agencies could include only the vehicle types covered by the final standards. And finally, it had a more updated projection of Chrysler sales.

LMC Automotive created a forecast that covered model years 2010-2025. Since the agencies used this forecast to generate the reference fleet (*i.e.*, the fleet expected to be sold absent any increases in the stringency regulations after the 2016 model year), it is important for the forecast to be independent of increases during 2017-2025 in the stringency of CAFE/ GHG standards. LMC Automotive does not use the CAFE or GHG standard as an input to their model, and specifically had no assumption of increase in stringency in the 2017-2025 time frame.

The agencies combined the LMC Automotive forecast with data from other sources to create the 2010 baseline reference fleet projections. This process is discussed in sections that follow.

1.4.2.2 How do the agencies develop the 2010 baseline 2017-2025 reference vehicle fleet?

The process of producing the MY 2010 baseline 2017-2025 reference fleet involved combining the baseline fleet with the projection data described above. This was a complex multistep procedure, which is described in this section. The procedure is new and some of the steps are different than those used with the MY2008 baseline fleet projection.

1.4.2.3 How was the 2010 baseline data merged with the LMC Automotive data?

EPA and NHTSA employed a different method from the method used in the NPRM for mapping certification vehicles to LMC Automotive (LMC) vehicles. Merging the 2010 baseline data with the 2017-2025 LMC data required a thorough mapping of certification vehicles to LMC vehicles by individual make and model. One challenge that the agencies faced when determining a reference case fleet was that the sales data projected by LMC had different market segmentation than the data contained in EPA's internal database. In order to create a common segmentation between the two databases, the agencies performed a side-by-side comparison of each vehicle model in both datasets, and created an additional "NEW SEGMENT" modifier in the spreadsheet to map the two datasets. The reference fleet sales based on the "NEW SEGMENT" was then projected.

The baseline data and reference fleet volumes are available to the public. The baseline Excel spreadsheet in the docket is the result of the merged files.[7] The spreadsheet provides specific details on the sources and definitions for the data. The Excel file contains several tabs. They are: "Data", "Data Tech Definitions", "SUM", "SUM Tech Definitions", "Truck Vehicle Type Map", and "Car Vehicle Type Map". "Data" is the tab with the raw data. "Data Tech Definitions" is the tab where each column is defined and its data source named. "SUM" is the tab where the raw data is processed to be used in the OMEGA and Volpe models. The "SUM" tab minus columns A-F and minus the Generic vehicles is the input file for the models. The "Generic" manufacturer (shown in the "SUM" tab) is the sum of all manufacturers and is calculated as a reference, and for data verification purposes. It is used to validate the manufacturers' totals. It also gives an overview of the fleet.

Table 1-6 shows some of the unique models chosen from the "SUM" tab. A model is made up of a unique combination of segment and vehicle type. The number of models is determined by the number of unique segment and vehicle type combinations. These combinations of segment and vehicle type (the vehicle type number is the same as the technology package number) are determined by the technology packages discussed in the EPA RIA. "SUM Tech Definitions" is the tab where the columns of the "SUM" tab are defined.

Table 1-25 Models from the SUM Tab Model

Model
Car Like LargeSuv I4 Vehicle Type: 7
Car Like LargeSuv I4, V6 Vehicle Type: 8
Car Like LargeSuv V6 Vehicle Type: 9
Car Like MidSizeSuv I4 Vehicle Type: 7
Car Like MidSizeSuv I4, V6 Vehicle Type: 8
Car Like MidSizeSuv V6 Vehicle Type: 9
Car Like SmallSuv V6 Vehicle Type: 10
LargeAuto V6 Vehicle Type: 3
LargeAuto V6 Vehicle Type: 4
LargeAuto >=V6 Vehicle Type: 5
LargeAuto >=V8 Vehicle Type: 6
MidSizeAuto I4 Vehicle Type: 2
MidSizeAuto I4, V6 Vehicle Type: 3
MidSizeAuto V6 Vehicle Type: 4
MidSizeAuto >=V6 Vehicle Type: 5
MidSizeAuto V8 Vehicle Type: 6

In the combined EPA certification and LMC data, all 2010 vehicle models were assumed to continue out to 2025, though their volumes changed in proportion to LMC projections. Also, any new models expected to be introduced within the 2011-2025 timeframe are not included in the data. These volumes are reassigned to the existing models to keep the overall fleet volume the same. All MYs 2017-2025 vehicles are mapped to the existing vehicles by a process of mapping to manufacturer's future segment volumes. The mappings are discussed in the next section. Further discussion of this limitation is discussed below in section 1.4.2.4. The statistics of this fleet will be presented below since further modifications were required to the volumes as the next section describes.

1.4.2.4 How were the LMC forecast and the AEO forecast used to project the future fleet volumes?

As with the comparable step in the MY 2008 baseline 2017-2025 reference fleet process, the next step in the agencies' generation of the reference fleet is one of the more complicated steps to explain. First, the 2010 CAFE data was mapped to the LMC segments. Second, the breakdown of segment volumes by manufacturer was compared between the LMC and CAFE data sets. Third, a correction was applied for Class 2B vehicles (Large Pickup Trucks) in the LMC data. Fourth, the individual manufacturer segment multipliers were created by year. And finally, the absolute volumes of cars and trucks were normalized (set equal) to the total sales estimates of the Early Release of the 2012 Annual Energy Outlook (AEO).

The process started with mapping the LMC segments to the CAFE data. The process was simple yet time consuming. The mapping required determining the LMC segment by looking at each of the 1171 vehicles in the LMC quarter forecast, and labeling it in the "New Segment" column of the new data spreadsheet. The segments were somewhat different from the ones employed by CSM. LMC has 27 segments and CSM has 18 segments. Table 1-26 has both the LMC Segments and the CSM segments for reference. Table 1-27 shows some of the Chrysler/Fiat[r] vehicles in the CAFE data with their "New Segment" identified.

Table 1-26 List of LMC Segments and CSM Segments

LMC Segments	CSM Class
Compact Conventional	Full-Size Car
Compact CUV	Full-Size CUV
Compact MPV	Full-Size Pickup
Compact Premium Conventional	Full-Size SUV
Compact Premium CUV	Full-Size Van
Compact Premium Sporty	Luxury Car
Compact Sporty	Mid-Size Car
Compact Utility	Mid-Size CUV
Large Conventional	Mid-Size MAV
Large Pickup	Mid-Size Pickup
Large Premium Conventional	Mid-Size SUV
Large Premium Sporty	Mid-Size Van
Large Premium Utility	Mini Car
Large Utility	Small Car
Large Van	Small CUV
Midsize Conventional	Small MAV
Midsize CUV	Small SUV
Midsize Pickup	Specialty Car
Midsize Premium Conventional	
Midsize Premium CUV	
Midsize Premium Sporty	
Midsize Premium Utility	

[r] Chrysler/Fiat is being used as an example throughout this section to make the example calculations easier to follow.

Midsize Sporty
Midsize Utility
Midsize Van

Table 1-27 Example of Chrysler/Fiat vehicles being mapped to segments based on the LMC Forecast

Manufacturer	Name Plate	Model	NEW SEGMENT
Chrysler/Fiat	Chrysler	300 AWD	Large Conventional
Chrysler/Fiat	Chrysler	PT Cruiser	Compact MPV
Chrysler/Fiat	Chrysler	Sebring	Midsize Conventional
Chrysler/Fiat	Chrysler	Town & Country FWD	Midsize Van
Chrysler/Fiat	Dodge	Caliber	Compact Conventional
Chrysler/Fiat	Dodge	Challenger	Midsize Sporty
Chrysler/Fiat	Dodge	Charger	Large Conventional
Chrysler/Fiat	Dodge	Dakota Pickup 2wd	Midsize Pickup
Chrysler/Fiat	Dodge	Grand Caravan FWD	Midsize Van
Chrysler/Fiat	Dodge	Journey 2wd	Midsize CUV

In this next step, segment volume by manufacturer was compared between the LMC and CAFE data sets. This is necessary to determine if all of the segments a manufacturer will produce in the future are currently represented by the 2010 CAFE data. Almost all the future segments matched the current segments with the exception of some premium vs. standard class vehicles. In cases where there was not a vehicle model in a premium class (such as Compact Premium CUV) in the future, but there was a model in the standard class (Compact CUV), the future premium class volume was added to the standard class volume. The same thing was done if the opposite was true, *i.e.* if there was not a vehicle in a standard class (such as Compact CUV) in the future, but there was one in the premium class (Compact Premium CUV), the future standard class volume was added to the premium class volume. Table 1-28 shows the New Segments, the LMC 2010 Volumes, and the LMC 2018 Volumes for Chrysler/Fiat. The Compact Premium Conventional, Compact Premium CUV, and Compact Premium Sporty were not available from Chrysler/Fiat in 2010, but are available in 2018. As mentioned, the volumes from all three of those premium segments were added to the standard segments Compact Conventional, Compact CUV, and Compact Sporty in years were the premium segments were produced.

Table 1-28 Example Chrysler/Fiat 2010 Volumes by Segment from the LMC Forecast

NEW SEGMENT	LMC 2010 Volume	LMC 2018 Volume
Compact Conventional	45,082	91,136
Compact CUV	54,514	78,307
Compact MPV	9,440	61,461
Compact Premium Conventional	-	35,027
Compact Premium CUV	-	12,783
Compact Premium Sporty	-	209
Compact Utility	166,492	210,979
Large Conventional	112,513	185,553
Large Pickup	199,652	284,583
Large Van	-	-

Midsize Conventional	89,508	88,007
Midsize CUV	48,577	91,880
Midsize Pickup	13,047	27,141
Midsize Premium Conventional	-	9,309
Midsize Premium CUV	-	12,476
Midsize Premium Sporty	392	3,014
Midsize Sporty	36,791	-
Midsize Utility	93,352	154,401
Midsize Van	215,598	155,408
Sub-Compact Conventional	-	97,342

A step that is related to the comparison step is the filtering of Class 2b vehicles from the LMC forecast. LMC includes Class 2b vehicles (vans and large pickup trucks) in its light-duty forecast. Class 2b vans are all appropriately classified as MDPVs (Medium Duty Passenger Vehicles) and must be included in the forecast since they are regulated under the light-duty CAFE and GHG programs. Class 2b large pickup trucks, however, are not regulated under the light-duty CAFE and GHG programs (rather under the medium- and heavy-duty fuel efficiency and GHG programs, see 76 FR at 57120), and must therefore be removed from the forecast. This is accomplished by a creating a multiplier for each manufacturer's large pickup trucks and applying it to each manufacturer's large pickup truck volume every model year in the LMC forecast; specifically, by taking a manufacturer's 2010 model year large pickup CAFE volume and dividing its 2010 model year large pickup LMC volume. Table 1-29 shows the volumes and the resulting multiplier for Chrysler/Fiat, while

Table **1-30** shows the 2025 LMC volume, the multiplier and the result of applying the multiplier to the original volume for Chrysler/Fiat.

Table 1-29 Example Values Used to Determine the Class 2b Truck Multiplier for Chrysler/Fiat

Manufacturer	NEW SEGMENT	LMC 2010 Volume	2010 CAFE Volume	Truck Multiplier
Chrysler/Fiat	Large Pickup	199,652	120,645	0.60

Table 1-30 Example Values Used to Determine Chrysler/Fiat's 2025 Truck Volume

Manufacturer	NEW SEGMENT	Original 2025 Volume	Truck Multiplier	2025 Volume after Multiplier
Chrysler/Fiat	Large Pickup	382,492	0.60	231,131

After correcting for Class 2b vehicles being in the LMC forecast, it was time to create individual manufacturer segment multipliers to be used with the individual 2010 CAFE vehicle volumes to create projections for the future fleet. The individual manufacturer segment multipliers are created by dividing each year of the LMC forecast's individual manufacturer segment volume by the manufacturer's individual segment volume determined using 2010 CAFE data. Table 1-31 has the 2010 CAFE Volume, the 2025 LMC large pickup volume after Class 2b vehicles were removed, and the individual manufacturer volume for large pickup trucks. The multiplier is the result of dividing the 2025 volume by the 2010 volume.

Table 1-31 Example Values Used to Determine Chrysler/Fiat 2025 Individual Large Pickup Multiplier

Manufacturer	NEW SEGMENT	2010 Cafe Volume	2025 Volume after Multiplier	Fiat/Chrysler Individual Large Pickup Multiplier for 2025
Chrysler/Fiat	Large Pickup	120,645	231,131	192%

Now that the individual manufacturer segment multipliers are calculated, they can be applied to each vehicle in the 2010 CAFE data. The segment multipliers are applied by multiplying the 2010 CAFE volume for a vehicle by the multiplier for its manufacturer and segment. Table 1-32 shows the 2010 CAFE volumes, the individual manufacturer segment multipliers, and the result of multiplying the multiplier and the volume for 2025 project volumes for many of Chrysler/Fiat's large pickup trucks.

Table 1-32 Example Applying the Individual Large Pickup Multiplier for Chrysler/Fiat

Manufacturer	Model	NEW SEGMENT	2010 CAFE Volume	Fiat/Chrysler Individual Large Pickup Multiplier for 2025	2025 Project Volume Before AEO Normalization
Chrysler/Fiat	Ram 1500 Pickup 2wd	Large Pickup	23,686	192%	45,377
Chrysler/Fiat	Ram 1500 Pickup 2wd	Large Pickup	938	192%	1,797
Chrysler/Fiat	Ram 1500 Pickup 2wd	Large Pickup	3,029	192%	5,803
Chrysler/Fiat	Ram 1500 Pickup 2wd	Large Pickup	16,505	192%	31,620
Chrysler/Fiat	Ram 1500 Pickup 2wd	Large Pickup	7,698	192%	14,748
Chrysler/Fiat	Ram 1500 Pickup 4wd	Large Pickup	1,162	192%	2,226
Chrysler/Fiat	Ram 1500 Pickup 4wd	Large Pickup	51,417	192%	98,504
Chrysler/Fiat	Ram 1500 Pickup 4wd	Large Pickup	15,498	192%	29,691
Chrysler/Fiat	Ram 1500 Pickup 4wd	Large Pickup	712	192%	1,364

Normalizing to AEO forecast for cars and trucks must be done once the individual manufacturer segment multipliers have been applied to all vehicles across every year (2011-2025) of the LMC forecast. In order to normalize a year, the number of trucks and the number of cars produced must be determined. Then, the truck and car totals from AEO are used to determine a normalizing multiplier. Table 1-33 has the 2025 car and truck totals before normalization, the 2025 AEO car and truck total, and the multipliers which are the result of dividing the AEO totals by totals before normalization.

Table 1-33 Example 2025 AEO Truck and Car Multipliers

Vehicle Type	2025 Total before Normalization	2025 AEO Total	AEO 2025 Normalizing Multiplier
Trucks	8,242,936	6,929,100	84%
Cars	8,954,382	9,525,700	106%

The final step in creating the reference volumes is applying the AEO multipliers. The AEO multipliers are applied by vehicle type. Table 1-34 shows the normalized volume, the AEO 2025 truck multiplier, and the final resulting volume for a number of Chrysler/Fiat pickups.

Table 1-34 Example Applying the AEO Truck Multiplier to Chrysler/Fiat Pickups

Manufacturer	Model	Vehicle Type	2025 Project Volume Before AEO Normalization	AEO 2025 Truck Multiplier	2025 Project Volume with AEO Normalization
Chrysler/Fiat	Ram 1500 Pickup 2wd	Truck	45,377	84%	38,145
Chrysler/Fiat	Ram 1500 Pickup 2wd	Truck	1,797	84%	1,511
Chrysler/Fiat	Ram 1500 Pickup 2wd	Truck	5,803	84%	4,878
Chrysler/Fiat	Ram 1500 Pickup 2wd	Truck	31,620	84%	26,580
Chrysler/Fiat	Ram 1500 Pickup 2wd	Truck	14,748	84%	12,397
Chrysler/Fiat	Ram 1500 Pickup 4wd	Truck	2,226	84%	1,871
Chrysler/Fiat	Ram 1500 Pickup 4wd	Truck	98,504	84%	82,804
Chrysler/Fiat	Ram 1500 Pickup 4wd	Truck	29,691	84%	24,959
Chrysler/Fiat	Ram 1500 Pickup 4wd	Truck	1,364	84%	1,147

1.4.3 What are the sales volumes and characteristics of the MY 2010 based reference fleet?

Table 1-35 and Table 1-37 below contain the sales volumes that result from the process above for MY 2010 and 2017-2020.

Table 1-36 and Table 1-38 below contain the sales volumes that result from the process above for MY 2021-2025.

Table 1-35 Vehicle Segment Volumes[a]

Reference Class Segment	Actual and Projected Sales Volume				
	2010	2017	2018	2019	2020
Large Auto	393,049	567,514	579,808	598,784	617,135

Mid-Size Auto	2,189,552	3,446,643	3,413,476	3,523,692	3,577,767
Compact Auto	1,894,017	2,561,669	2,525,760	2,524,658	2,537,591
Sub-Compact Auto	1,615,536	2,258,243	2,231,633	2,161,935	2,169,551
Large Pickup	1,201,518	1,747,062	1,723,045	1,773,581	1,757,204
Small Pickup	74,780	39,095	39,793	49,185	55,481
Large SUV	2,066,629	3,259,969	3,208,284	3,157,778	3,086,726
Mid-Size SUV	1,058,340	1,068,111	1,036,455	1,058,492	1,037,464
Small SUV	113,716	148,142	143,413	142,957	142,894
Mini Van	565,527	686,492	674,803	641,731	618,567
Cargo Van	17,516	29,160	28,929	29,308	29,821

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table 1-36 Vehicle Segment Volumes[a]

Reference Class	Projected Sales Volume				
Segment	2021	2022	2023	2024	2025
Large Auto	627,571	641,252	657,367	665,152	678,652
Mid-Size Auto	3,644,746	3,684,993	3,763,193	3,819,396	3,902,811
Compact Auto	2,571,913	2,613,050	2,649,239	2,709,562	2,750,233
Sub-Compact Auto	2,188,554	2,236,339	2,256,403	2,334,855	2,359,545
Large Pickup	1,759,426	1,761,341	1,763,299	1,770,423	1,787,445
Small Pickup	58,848	62,556	66,735	71,587	75,596
Large SUV	3,067,335	3,064,546	3,043,294	3,049,618	3,064,625
Mid-Size SUV	1,026,207	1,040,034	1,031,240	1,047,527	1,052,812
Small SUV	143,576	145,165	146,476	148,201	152,103
Mini Van	612,054	607,502	599,255	600,002	599,779
Cargo Van	29,868	30,422	30,699	30,678	31,198

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table 1-37 2011+ NHTSA Car and Truck Definition Based Volumes

Vehicle Type	Actual and Projected Sales Volume				
	2010	2017	2018	2019	2020
Cars	7,176,330	10,213,312	10,088,966	10,139,761	10,194,353
Trucks	4,013,850	5,598,788	5,516,434	5,522,339	5,435,847
Cars and Trucks	11,190,180	15,812,100	15,605,400	15,662,100	15,630,200

Table 1-38 2011+ NHTSA Car and Truck Definition Based Volumes

Vehicle Type	Projected Sales Volume				
	2021	2022	2023	2024	2025
Cars	10,310,594	10,455,061	10,593,727	10,811,530	10,981,082
Trucks	5,419,506	5,432,139	5,413,473	5,435,470	5,473,718
Cars and Trucks	15,730,100	15,887,200	16,007,200	16,247,000	16,454,800

Table 1-40 and Table 1-40 below contain the sales volumes by manufacturer and vehicle type for MY 2010 and 2017-2025. Tesla did not report any vehicle sales in 2010 so their projected volume is zero. Spyker/Saab sold no vehicles under the Spyker brand in 2010 so their volume is also zero.

Table 1-39 NHTSA Car and Truck Definition Manufacturer Volumes

Manufacturers	Vehicl e Type	2010 Baseline Sales	2017 Projected Volume	2018 Projected Volume	2019 Projected Volume	2020 Projected Volume
All	Both	11,190,180	11,190,180	15,605,400	15,662,100	15,630,200
All	Cars	7,176,330	10,213,312	10,088,966	10,139,761	10,194,353
All	Trucks	4,013,850	5,598,788	5,516,434	5,522,339	5,435,847
Aston Martin	Cars	601	634	617	620	620
Aston Martin	Trucks	-	-	-	-	-
BMW	Cars	143,638	320,634	318,821	327,091	329,304
BMW	Trucks	26,788	106,150	104,625	105,104	101,805
Chrysler/Fiat	Cars	496,998	728,817	736,022	769,256	786,344
Chrysler/Fiat	Trucks	665,806	774,065	743,375	749,206	740,640
Daimler	Cars	157,453	252,820	240,222	245,807	245,888
Daimler	Trucks	72,393	99,125	108,510	108,294	108,598
Ferrari	Cars	1,780	1,878	1,828	1,836	1,837
Ferrari	Trucks	-	-	-	-	-
Ford	Cars	940,241	1,348,543	1,347,544	1,341,628	1,347,596
Ford	Trucks	858,798	1,035,400	1,023,955	1,016,328	995,702
Geely	Cars	28,223	60,422	57,655	60,338	60,040
Geely	Trucks	29,719	35,087	32,438	33,299	32,149
General Motors	Cars	1,010,524	1,652,946	1,616,449	1,611,415	1,612,666
General Motors	Trucks	735,367	1,213,192	1,201,479	1,217,167	1,211,435
Honda	Cars	845,318	1,122,558	1,139,856	1,147,055	1,167,627
Honda	Trucks	390,028	536,998	525,327	527,814	517,268
Hyundai	Cars	375,656	865,069	849,727	857,497	861,062
Hyundai	Trucks	35,360	131,912	127,289	122,193	118,265
Kia	Cars	226,157	345,314	339,180	328,872	327,694

Kia	Trucks	21,721	43,374	43,209	41,648	40,270
Lotus	Cars	354	374	364	365	365
Lotus	Trucks	-	-	-	-	-
Mazda	Cars	249,489	254,270	249,048	247,203	248,350
Mazda	Trucks	61,451	59,862	59,114	55,108	53,334
Mitsubishi	Cars	54,263	61,058	58,152	60,387	60,619
Mitsubishi	Trucks	9,146	13,701	13,840	14,276	14,262
Nissan	Cars	619,918	889,039	867,771	873,076	874,098
Nissan	Trucks	255,566	305,943	306,537	309,179	304,196
Porsche	Cars	11,937	18,430	18,138	17,255	17,065
Porsche	Trucks	3,978	20,105	19,647	19,573	18,851
Spyker/Saab	Cars	-	-	-	-	-
Spyker/Saab	Trucks	-	-	-	-	-
Subaru	Cars	184,587	209,137	205,550	205,868	205,749
Subaru	Trucks	73,665	96,938	94,441	92,177	90,751
Suzuki	Cars	25,002	43,253	42,515	43,399	44,081
Suzuki	Trucks	3,938	3,399	3,347	3,690	3,676
Tata/JLR	Cars	11,279	28,012	27,188	28,194	28,430
Tata/JLR	Trucks	37,475	54,033	53,423	52,682	51,461
Tesla	Cars	-	-	-	-	-
Tesla	Trucks	-	-	-	-	-
Toyota	Cars	1,508,866	1,528,208	1,501,492	1,509,270	1,515,051
Toyota	Trucks	696,324	966,417	955,281	951,691	932,267
Volkswagen	Cars	284,046	481,894	470,826	463,329	459,868
Volkswagen	Trucks	36,327	103,088	100,596	102,910	100,916

Table 1-40 NHTSA Car and Truck Definition Manufacturer Volumes

Manufacturers	Vehicle Type	2021 Projected Volume	2022 Projected Volume	2023 Projected Volume	2024 Projected Volume	2025 Projected Volume
All	Both	15,730,100	15,887,200	16,007,200	16,247,000	16,454,800
All	Cars	10,310,594	10,455,061	10,593,727	10,811,530	10,981,082
All	Trucks	5,419,506	5,432,139	5,413,473	5,435,470	5,473,718
Aston Martin	Cars	623	626	630	634	639
Aston Martin	Trucks	-	-	-	-	-
BMW	Cars	335,753	341,613	346,903	357,948	363,380
BMW	Trucks	101,238	100,345	99,084	101,174	101,013
Chrysler/Fiat	Cars	805,113	828,656	850,402	877,751	899,843
Chrysler/Fiat	Trucks	733,257	735,937	731,269	722,213	726,403
Daimler	Cars	249,219	251,461	253,688	258,742	261,242
Daimler	Trucks	110,235	112,133	113,550	116,867	119,090
Ferrari	Cars	1,845	1,853	1,865	1,878	1,894
Ferrari	Trucks	-	-	-	-	-
Ford	Cars	1,359,990	1,377,947	1,394,907	1,418,568	1,441,350
Ford	Trucks	990,243	990,827	985,782	991,767	997,694

Geely	Cars	61,433	62,399	63,076	65,157	65,883
Geely	Trucks	31,977	31,598	31,007	31,796	31,528
General Motors	Cars	1,624,561	1,638,066	1,652,324	1,676,558	1,696,474
General Motors	Trucks	1,218,265	1,226,184	1,232,502	1,244,178	1,261,546
Honda	Cars	1,187,756	1,212,900	1,238,278	1,267,745	1,295,234
Honda	Trucks	512,800	515,656	509,628	505,534	504,020
Hyundai	Cars	873,625	887,004	899,936	918,938	935,619
Hyundai	Trucks	117,565	116,208	115,339	116,430	117,662
Kia	Cars	330,416	335,846	338,791	346,828	350,765
Kia	Trucks	39,205	38,857	38,203	38,034	37,957
Lotus	Cars	367	368	371	374	377
Lotus	Trucks	-	-	-	-	-
Mazda	Cars	249,288	252,522	254,751	259,488	262,732
Mazda	Trucks	52,946	52,752	52,158	52,998	53,183
Mitsubishi	Cars	61,785	63,390	63,937	67,026	67,925
Mitsubishi	Trucks	14,307	14,778	14,824	15,229	15,464
Nissan	Cars	879,450	884,816	893,622	907,823	919,920
Nissan	Trucks	303,616	304,381	304,703	308,510	312,005
Porsche	Cars	17,289	17,216	17,292	17,517	17,609
Porsche	Trucks	18,863	18,598	18,562	18,861	19,091
Spyker	Cars	-	-	-	-	-
Spyker	Trucks	-	-	-	-	-
Subaru	Cars	206,863	209,828	211,621	215,567	218,870
Subaru	Trucks	91,673	91,940	92,337	94,300	96,326
Suzuki	Cars	44,765	45,769	46,590	47,824	48,710
Suzuki	Trucks	3,760	3,879	3,939	4,085	4,173
Tata/JLR	Cars	28,977	29,416	29,898	30,546	30,949
Tata/JLR	Trucks	50,984	50,767	50,280	50,340	50,369
Tesla	Cars	-	-	-	-	-
Tesla	Trucks	-	-	-	-	-
Toyota	Cars	1,530,699	1,548,354	1,567,676	1,598,715	1,622,242
Toyota	Trucks	927,227	925,277	918,749	918,479	921,183
Volkswagen	Cars	460,777	465,011	467,170	475,903	479,423
Volkswagen	Trucks	101,344	102,022	101,558	104,673	105,009

Table 1-41 also shows how the change in fleet make-up may affect the footprint distributions over time. The resulting data indicate that footprint will not change significantly between 2010 and 2025. The footprints are somewhat larger than in the 2008 based fleet projection (Table 1-19).

Table 1-41 Production Weighted Foot Print Mean

Model	Average Footprint of all	Average Footprint	Average Footprint

Year	Vehicles	Cars	Trucks
2010	48.6	45.2	54.5
2017	48.7	45.4	54.9
2018	48.8	45.4	54.9
2019	48.8	45.5	55.0
2020	48.8	45.5	55.0
2021	48.8	45.5	55.0
2022	48.7	45.5	55.0
2023	48.7	45.5	55.0
2024	48.6	45.5	54.9
2025	48.6	45.5	55.0

Table 1-42 below shows the changes in engine cylinders over the model years. The current assumptions show that engines will increase in size between 2010 and 2017 and then remain relatively constant over the model years to which these final rules apply.

Table 1-42 Percentages of 4, 6, 8 Cylinder Engines by Model Year

	Trucks			Cars		
Model Year	**4 Cylinders**	**6 Cylinders**	**8 Cylinders**	**4 Cylinders**	**6 Cylinders**	**8 Cylinders**
2010	15.7%	52.5%	31.8%	69.2%	26.6%	4.1%
2017	13.9%	50.2%	35.9%	66.3%	29.0%	4.7%
2018	13.7%	50.3%	36.0%	66.2%	29.1%	4.7%
2019	13.6%	50.0%	36.4%	65.7%	29.6%	4.7%
2020	13.5%	49.9%	36.7%	65.7%	29.6%	4.7%
2021	13.4%	49.8%	36.8%	65.7%	29.6%	4.7%
2022	13.5%	49.7%	36.8%	65.8%	29.5%	4.8%
2023	13.5%	49.6%	36.9%	65.7%	29.5%	4.8%
2024	13.7%	49.6%	36.8%	65.9%	29.4%	4.7%
2025	13.6%	49.5%	36.8%	65.9%	29.4%	4.8%

1.5 What are the differences in the sales volumes and characteristics of the MY 2008 based and the MY 2010 based reference fleets?

This section compares some of the differences between the fleet based on MY 2008 CAFE and the fleet based on MY 2010 CAFE data. As stated before, the 2008 fleet projection is based on MY 2008 CAFE data, a long range forecast provided by CSM, and interim AEO 2011. The 2010 fleet projection is based on MY 2010 CAFE, a long range forecast provided by LMC Automotive, and interim AEO 2012.

Table 1-43, Table 1-44, Table 1-45 and Table 1-46 below contain the sales volume differences between the two fleets, from subtracting the 2008 MY based fleet projection from the 2010 MY based fleet projection.

The sales in MY 2010 are significantly lower (by 2,661,581 vehicles) than in MY 2008 (reflecting the continued economic recession, as noted earlier). The sales in MY 2010 are depressed but sales are expected to recover to their MY 2008 levels before 2017.

There is an increase in the number of large trucks, midsize autos, and large autos by 2025. There is also decreased volume in the remaining segment in 2025. These differences are due to the LMC forecast and the newer AEO projection.

Table 1-43 Vehicle Segment Volumes Differences[a]

Reference Class Segment	Actual Sales Volume	Projected Sales Volume			
	2010-2008	2017	2018	2019	2020
LargeAuto	-169,191	191,407	223,040	245,175	222,271
MidSizeAuto	-909,375	135,375	123,068	220,071	195,982
CompactAuto	-85,444	213,689	200,367	155,357	89,570
SubCmpctAuto	249,703	-199,979	-222,479	-327,273	-383,799
LargePickup	-380,708	232,443	279,279	390,391	371,009
SmallPickup	-102,717	-117,132	-118,139	-111,567	-90,548
LargeSUV	-717,320	65,480	58,183	-20,090	-116,518
MidSizeSUV	-205,020	-290,644	-272,757	-208,902	-248,358
SmallSUV	-171,639	-109	-6,520	-11,718	-19,783
MiniVan	-76,528	-68,070	-64,748	-75,334	-95,756
CargoVan	-93,342	-156,681	-170,305	-172,666	-189,807

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table 1-44 Vehicle Segment Volumes Differences[a]

Reference Class Segment	Projected Sales Volume				
	2021	2022	2023	2024	2025
LargeAuto	247,379	282,957	294,695	308,979	309,809
MidSizeAuto	202,630	136,730	70,660	67,900	87,870
CompactAuto	50,936	20,851	16,313	-35,072	-92,836
SubCmpctAuto	-437,810	-450,828	-464,699	-461,206	-518,743
LargePickup	391,125	411,920	462,006	498,672	527,056
SmallPickup	-91,275	-84,582	-84,580	-83,040	-79,242
LargeSUV	-245,579	-298,062	-369,459	-426,255	-456,367
MidSizeSUV	-255,033	-243,210	-237,048	-245,135	-252,550
SmallSUV	-23,647	-24,478	-23,763	-24,990	-23,610
MiniVan	-117,024	-131,480	-141,530	-120,718	-126,477
CargoVan	-180,671	-172,390	-170,886	-166,222	-170,570

[a] Volumes in this table are based on the pre-2011 NHTSA definition of Cars and Trucks.

Table 1-45 2011+ NHTSA Car and Truck Definition Based Volumes Differences

Vehicle Type	Actual Sales Volume	Projected Sales Volume			
	2010 - 2008	2017	2018	2019	2020
Cars	-1,054,238	225,645	183,602	144,065	-97,209
Trucks	-1,607,343	-219,867	-154,612	-60,623	-168,530
Cars and Trucks	-2,661,581	5,778	28,990	83,442	-265,739

Table 1-46 2011+ NHTSA Car and Truck Definition Based Volumes Differences

Vehicle Type	Projected Sales Volume				
	2021	2022	2023	2024	2025
Cars	-194,571	-280,716	-374,276	-446,608	-560,478
Trucks	-264,396	-271,857	-274,013	-240,479	-235,181
Cars and Trucks	-458,966	-552,572	-648,289	-687,087	-795,659

Table 1-47 and Table 1-48 below contain the differences in sales volumes by manufacturer and vehicle type between the 2008 MY based fleet and the 2010 MY based fleet. Table 1-48 shows that Chrysler/Fiat cars and trucks, Ford trucks, Hyundai cars, and Porsche trucks are projected to have significant increases in volume in MY 2025, though Table 1-48 also shows the market down overall in MY 2025 by 795,659 vehicles.

Table 1-47 NHTSA Car and Truck Definition Manufacturer Volumes Differences

Manufacturers	Vehicle Type	2010-2008 Difference in Sales	2017 Difference in Volume	2018 Difference in Volume	2019 Difference in Volume	2020 Difference in Volume
All	Both	-2,661,581	-4,616,142	28,990	83,442	-265,739
All	Cars	-1,054,238	225,645	183,602	144,065	-97,209
All	Trucks	-1,607,343	-219,867	-154,612	-60,623	-168,530
Aston Martin	Cars	-769	-401	-434	-452	-414
Aston Martin	Trucks	NA	NA	NA	NA	NA
BMW	Cars	-148,158	7,612	-4,118	-18,984	-28,638
BMW	Trucks	-34,536	-31,903	-27,317	-26,269	-26,534
Chrysler/Fiat	Cars	-206,160	310,054	338,484	377,567	371,025
Chrysler/Fiat	Trucks	-290,986	364,363	355,517	382,759	379,963
Daimler	Cars	-50,742	-32,027	-36,187	-35,618	-45,101
Daimler	Trucks	-6,742	12,212	24,859	20,106	15,679
Ferrari	Cars	330	-4,798	-4,872	-4,958	-5,079
Ferrari	Trucks	NA	NA	NA	NA	NA
Ford	Cars	-16,458	48,644	36,077	9,589	-31,193
Ford	Trucks	44,604	271,851	275,126	298,555	278,665
Geely/Volvo	Cars	-4,525	18,535	15,468	17,213	17,425
Geely/Volvo	Trucks	-35,930	-53,147	-56,956	-58,276	-60,854
GM	Cars	-497,273	290,185	178,094	106,390	81,911
GM	Trucks	-852,024	-249,012	-272,597	-276,344	-333,548
HONDA	Cars	-161,321	-32,042	1,769	2,416	3,961
HONDA	Trucks	-115,112	-59,483	-19,292	279	-7,821
HYUNDAI	Cars	37,787	273,042	271,354	274,526	262,779
HYUNDAI	Trucks	-17,798	-20,973	-24,172	-33,449	-35,908
Kia	Cars	4,177	23,270	26,810	13,993	4,018
Kia	Trucks	-37,751	-55,328	-55,071	-59,031	-56,265
Lotus	Cars	102	134	121	115	99
Lotus	Trucks	NA	NA	NA	NA	NA
Mazda	Cars	2,828	730	-13,464	-19,748	-21,728
Mazda	Trucks	5,566	8,074	1,579	-2,386	-4,820
Mitsubishi	Cars	-31,095	-4,041	-5,519	-3,439	-4,461
Mitsubishi	Trucks	-6,225	-23,931	-22,460	-21,178	-20,953

Nissan	Cars	-97,951	18,242	18,093	18,676	-8,693
Nissan	Trucks	-49,980	-138,995	-105,846	-89,380	-93,673
PORSCHE	Cars	-6,972	-16,663	-17,306	-18,861	-18,898
PORSCHE	Trucks	-14,819	6,872	7,646	8,104	7,710
Spyker/Saab	Cars	NA	NA	NA	NA	NA
Spyker/Saab	Trucks	NA	NA	NA	NA	NA
Subaru	Cars	68,552	-14,975	-11,048	-11,227	-17,717
Subaru	Trucks	-8,881	18,696	19,289	19,345	18,293
Suzuki	Cars	-54,337	-47,455	-47,417	-47,169	-49,467
Suzuki	Trucks	-31,381	-18,710	-18,038	-17,002	-16,999
Tata/JLR	Cars	1,683	-27,869	-29,034	-29,073	-29,752
Tata/JLR	Trucks	-18,109	-3,546	-3,183	-5,172	-4,752
Tesla	Cars	NA	NA	NA	NA	NA
Tesla	Trucks	NA	NA	NA	NA	NA
Toyota	Cars	248,502	-320,988	-332,689	-327,036	-368,683
Toyota	Trucks	-254,812	-364,094	-268,134	-190,413	-222,037
Volkswagen	Cars	-7,437	-69,744	-69,210	-73,785	-94,954
Volkswagen	Trucks	9,328	-25,731	-44,895	-43,981	-45,784

Table 1-48 NHTSA Car and Truck Definition Manufacturer Volumes Differences

Manufacturers	Vehicle Type	2021 Difference in Volume	2022 Difference in Volume	2023 Difference in Volume	2024 Difference in Volume	2025 Difference in Volume
All	Both	-458,966	-552,572	-648,289	-687,087	-795,659
All	Cars	-194,571	-280,716	-374,276	-446,608	-560,478
All	Trucks	-264,396	-271,857	-274,013	-240,479	-235,181
Aston Martin	Cars	-435	-423	-411	-507	-543
Aston Martin	Trucks	NA	NA	NA	NA	NA
BMW	Cars	-23,345	-18,421	-13,658	-30,245	-41,876
BMW	Trucks	-27,486	-28,554	-28,437	-45,351	-44,396
Chrysler/Fiat	Cars	384,100	404,483	426,520	451,734	463,364
Chrysler/Fiat	Trucks	384,644	372,929	370,205	377,251	394,641
Daimler	Cars	-51,159	-53,277	-58,819	-73,595	-79,477
Daimler	Trucks	10,786	11,198	8,235	9,783	18,023
Ferrari	Cars	-5,214	-5,285	-5,362	-5,563	-5,764
Ferrari	Trucks	NA	NA	NA	NA	NA
Ford	Cars	-41,627	-37,274	-79,890	-85,102	-98,759
Ford	Trucks	276,062	276,561	285,777	302,913	313,218
Geely/JLR	Cars	19,665	20,713	21,045	22,696	23,295
Geely/JLR	Trucks	-60,749	-60,914	-65,833	-67,385	-69,579
GM	Cars	94,541	130,413	155,505	182,961	172,466
GM	Trucks	-346,012	-352,372	-373,993	-392,627	-412,390

HONDA	Cars	-11,124	-24,604	-27,286	-40,106	-45,087
HONDA	Trucks	-23,116	-23,579	-27,270	-31,460	-53,677
HYUNDAI	Cars	260,270	259,040	265,628	261,228	258,369
HYUNDAI	Trucks	-38,901	-41,285	-45,850	-49,662	-50,474
Kia	Cars	-903	-3,256	-3,955	-5,054	-12,018
Kia	Trucks	-56,227	-55,837	-57,485	-58,085	-59,696
Lotus	Cars	89	78	72	66	61
Lotus	Trucks	NA	NA	NA	NA	NA
Mazda	Cars	-25,452	-28,628	-42,159	-41,126	-44,072
Mazda	Trucks	-6,281	-7,555	-9,808	-8,973	-8,185
Mitsubishi	Cars	-4,066	-3,871	-3,743	-3,702	-5,380
Mitsubishi	Trucks	-21,002	-20,449	-20,645	-20,772	-20,923
Nissan	Cars	-33,179	-52,631	-60,718	-74,948	-94,855
Nissan	Trucks	-104,413	-107,502	-112,418	-113,707	-114,449
PORSCHE	Cars	-19,186	-19,391	-19,701	-21,987	-23,087
PORSCHE	Trucks	7,621	7,213	7,192	7,452	7,872
Spyker/Saab	Cars	NA	NA	NA	NA	NA
Spyker/Saab	Trucks	NA	NA	NA	NA	NA
Subaru	Cars	-23,917	-28,785	-29,991	-32,716	-38,100
Subaru	Trucks	18,900	19,204	19,315	20,158	21,604
Suzuki	Cars	-50,960	-51,830	-52,673	-52,623	-54,444
Suzuki	Trucks	-17,007	-16,855	-16,864	-17,077	-17,201
Tata/JLR	Cars	-29,700	-29,933	-30,741	-33,182	-34,469
Tata/JLR	Trucks	-7,169	-7,823	-8,585	-7,641	-6,436
Tesla	Cars	NA	NA	NA	NA	NA
Tesla	Trucks	NA	NA	NA	NA	NA
Toyota	Cars	-373,007	-437,723	-469,316	-481,813	-485,811
Toyota	Trucks	-288,312	-309,775	-306,231	-289,534	-288,833
Volkswagen	Cars	-124,830	-128,303	-129,579	-129,433	-150,740
Volkswagen	Trucks	-47,390	-44,728	-52,369	-52,266	-49,275

Table 1-49 shows the difference in footprint distributions between the 2010 based fleet projection and the 2008 based fleet projection. The differences between MYs 2010 and 2008 are small and are just the result of the manufacturers' product mix in those model years. MY 2025 shows an increase in both the average truck and average car footprints. This is due to the increased number of large cars and large trucks forecast in the 2010 based fleet projection. Also, in several MYs, the change in the average footprint of all vehicles is outside the range between the changes in the corresponding car and truck fleets. This is due to production weighting. Because the total numbers of cars and trucks differs, production weighting can affect the average for the whole fleet as compared to the averages for cars and trucks. This can cause a counterintuitive effect when taking the difference of the averages.

Table 1-49 Production Weighted Foot Print Mean Difference*

Model Year	Average Footprint of all Vehicles	Average Footprint Cars	Average Footprint Trucks
2010-2008	48.6 - 48.8 = **-0.2**	45.2 – 45.2 = **0.0**	54.5 - 53.9 = **0.6**
2017	48.7 - 48.0 = **0.7**	45.4 - 44.6 = **0.8**	54.9 - 53.8 = **1.1**
2018	48.8 - 47.9 = **0.9**	45.4 - 44.6 = **0.8**	54.9 - 53.7 = **1.2**
2019	48.8 - 47.8 = **1.0**	45.5 - 44.6 = **0.9**	55.0 - 53.6 = **1.4**
2020	48.8 - 47.8 = **1.0**	45.5 - 44.6 = **0.9**	55.0 - 53.7 = **1.3**
2021	48.8 - 47.7 = **1.0**	45.5 - 44.6 = **0.9**	55.0 - 53.6 = **1.4**
2022	48.7 - 47.7 = **1.0**	45.5 - 44.6 = **0.9**	55.0 - 53.6 = **1.4**
2023	48.7 - 47.7 = **1.0**	45.5 - 44.6 = **0.9**	55.0 - 53.5 = **1.5**
2024	48.6 - 47.5 = **1.1**	45.5 - 44.6 = **0.9**	54.9 - 53.3 = **1.6**
2025	48.6 - 47.5 = **1.1**	45.5 - 44.6 = **0.9**	55.0 - 53.3 = **1.7**

***Note: This table is the difference calculated from Table 1-19 and Table 1-41.**

Table 1-50 shows the difference in engine cylinders distribution between the 2010 MY based fleet and the 2008 MY based fleet. MY 2010 has fewer vehicles with 6 cylinder engines. Fewer 6 cylinders in the baseline fleet along with vehicle mix changes results in more 4 and 8 cylinder engines in trucks and more 4 cylinder cars by 2025.

Table 1-50 Differences in Percentages of 4, 6, 8 Cylinder Engines by Model Year

	Trucks			Cars		
Model Year	**4 Cylinders**	**6 Cylinders**	**8 Cylinders**	**4 Cylinders**	**6 Cylinders**	**8 Cylinders**
2010-2008	5.40%	-3.90%	-1.50%	12.30%	-11.20%	-1.20%
2017	3.00%	-13.50%	10.50%	5.70%	-5.50%	-0.30%
2018	3.10%	-14.20%	11.20%	5.50%	-5.30%	-0.30%
2019	3.20%	-15.50%	12.30%	5.00%	-4.70%	-0.30%
2020	3.20%	-15.70%	12.60%	5.40%	-5.10%	-0.30%
2021	3.10%	-16.50%	13.40%	5.10%	-4.80%	-0.20%
2022	3.20%	-17.00%	13.80%	4.70%	-4.70%	0.00%
2023	3.20%	-18.10%	14.90%	4.80%	-4.80%	0.00%
2024	3.20%	-18.50%	15.40%	4.90%	-4.70%	-0.10%
2025	3.10%	-18.70%	15.50%	4.80%	-4.60%	0.00%

References:

[1] EPA's Omega Model and input sheets are available at http://www.epa.gov/oms/climate/models.htm; DOT/NHTSA's CAFE Compliance and Effects Modeling System (commonly known as the "Volpe Model") and input and output sheets are available at http://www.nhtsa.gov/fuel-economy. It is also available in the docket (Docket EPA-HQ-OAR-2010-0799)

[2] http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/CAFE+Compliance+and+Effects+Modeling+System:+The+Volpe+Model

[3] Department of Energy, Energy Information Administration, Annual Energy Outlook (AEO) 2011, Early Release. *Available at* http://www.eia.gov/forecasts/aeo/.

[4] The baseline Excel file ("2008-2025 Production Summary Data _Definitions Docket 08_27_2009") is available in the docket (Docket EPA-HQ-OAR-2010-0799).

[5] http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/CAFE+Compliance+and+Effects+Modeling+System:+The+Volpe+Model

[6] Department of Energy, Energy Information Administration, Annual Energy Outlook (AEO) 20112012, Early Release. *Available at* http://www.eia.gov/forecasts/aeo/ (last accessed Aug. 15, 2011April 9, 2012).

[7] The baseline Excel file ("2010-2025 Production Summary Data_Definitions Docket 05.01.2012") is available in the docket (Docket EPA-HQ-OAR-2010-0799).

Chapter 2: What are the Attribute-Based Curves the Agencies are Adopting, and How Were They Developed?

2.1 Why are standards attribute-based and defined by a mathematical function?

As in the MYs 2012-2016 CAFE/GHG rules, and as NHTSA did in the MY 2011 CAFE rule, NHTSA and EPA are promulgating attribute-based CAFE and CO_2 standards that are defined by a mathematical function. EPCA, as amended by EISA, expressly requires that CAFE standards for passenger cars and light trucks be based on one or more vehicle attributes related to fuel economy, and be expressed in the form of a mathematical function.[1] The CAA has no such requirement, although such an approach is permissible under section 202 (a) and EPA has used the attribute-based approach in issuing standards under both section 202 (a) and under analogous provisions of the CAA (*e.g.*, criteria pollutant standards for non-road diesel engines using engine size as the attribute,[2] in the recent GHG standards for heavy duty pickups and vans using a work factor attribute,[3] and in the MYs 2012-2016 GHG rule which used vehicle footprint as the attribute). Public comments on the MYs 2012-2016 rulemaking widely supported attribute-based standards for both agencies' standards. Comments received on the MY 2017 and later proposal also generally supported an attribute-based standard, as further discussed in section 2.2.

Under an attribute-based standard, every vehicle model has a performance target (fuel economy and CO_2 emissions for CAFE and CO_2 emissions standards, respectively), the level of which depends on the vehicle's attribute (for this rule, footprint, as discussed below). The manufacturers' fleet average performance is determined by the production-weighted[a] average (for CAFE, harmonic average) of those targets.

The agencies believe that an attribute-based standard is preferable to a single-industry-wide average standard in the context of CAFE and CO_2 standards for several reasons. First, if the shape is chosen properly, every manufacturer is more likely to be required to continue adding more fuel efficient technology each year across their fleet, because the stringency of the compliance obligation will depend on the particular product mix of each manufacturer. Therefore a maximum feasible attribute-based standard will tend to require greater fuel savings and CO_2 emissions reductions overall than would a maximum feasible flat standard (that is, a single mpg or CO_2 level applicable to every manufacturer).

Second, depending on the attribute, attribute-based standards reduce the incentive for manufacturers to respond to CAFE and CO_2 standards in ways harmful to safety.[b] Because

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[a] Production for sale in the United States.

[b] The 2002 NAS Report described at length and quantified the potential safety problem with average fuel economy standards that specify a single numerical requirement for the entire industry. *See* 2002 NAS Report at 5, finding 12. Ensuing analyses, including by NHTSA, support the fundamental conclusion that standards structured to minimize incentives to downsize all but the largest vehicles will tend to produce better safety outcomes than flat standards.

each vehicle model has its own target (based on the attribute chosen), properly fitted attribute-based standards provide little, if any, incentive to build smaller vehicles simply to meet a fleet-wide average, because the smaller vehicles will be subject to more stringent compliance targets.[c]

Third, attribute-based standards provide a more equitable regulatory framework for different vehicle manufacturers.[d] A single industry-wide average standard imposes disproportionate cost burdens and compliance difficulties on the manufacturers that need to change their product plans to meet the standards, and puts no obligation on those manufacturers that have no need to change their plans. As discussed above, attribute-based standards help to spread the regulatory cost burden for fuel economy more broadly across all of the vehicle manufacturers within the industry.

Fourth, attribute-based standards better respect economic conditions and consumer choice, as compared to single-value standards. A flat, or single value, standard encourages a certain vehicle size fleet mix by creating incentives for manufacturers to use vehicle downsizing as a compliance strategy. Under a footprint-based standard, manufacturers have greater incentive (compared to under a flat standard) to invest in technologies that improve the fuel economy of the vehicles they sell rather than shifting product mix, because reducing the size of the vehicle is generally a less viable compliance strategy given that smaller vehicles have more stringent regulatory targets.

2.2 What attribute are the agencies adopting, and why?

As in the MYs 2012-2016 CAFE/GHG rules, and as NHTSA did in the MY 2011 CAFE rule, NHTSA and EPA are promulgating CAFE and CO_2 standards that are based on vehicle footprint, which has an observable correlation to fuel economy and emissions. There are several policy and technical reasons why NHTSA and EPA believe that footprint is the most appropriate attribute on which to base the standards for the vehicles covered by this rulemaking, even though some other light-duty vehicle attributes (notably curb weight) are better correlated to fuel economy and emissions.

First, in the agencies' judgment, from the standpoint of vehicle safety, it is important that the CAFE and CO_2 standards be set in a way that does not encourage manufacturers to respond by selling vehicles that are less safe. NHTSA's research of historical crash data has found that reductions in vehicle size and reductions in the mass of lighter vehicles tend to compromise overall highway safety, while reductions in the mass of heavier vehicles tend to improve overall highway safety. If footprint-based standards are defined in a way that creates relatively uniform burden for compliance for vehicles of all sizes, then footprint-based standards will not incentivize manufacturers to downsize their fleets as a strategy for

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[c] Assuming that the attribute is related to vehicle size.
[d] *Id*. at 4-5, finding 10.

compliance which could compromise societal safety, or to upsize their fleets which might reduce the program's fuel savings and GHG emission reduction benefits. Footprint-based standards also enable manufacturers to apply weight-efficient materials and designs to their vehicles while maintaining footprint, as an effective means to improve fuel economy and reduce GHG emissions. On the other hand, depending on their design, weight-based standards can create disincentives for manufacturers to apply weight-efficient materials and designs. This is because weight-based standards would become more stringent as vehicle mass is reduced. The agencies discuss mass reduction and its relation to safety in more detail in Preamble section II.G.

Further, although we recognize that weight is better correlated with fuel economy and CO_2 emissions than is footprint, we continue to believe that there is less risk of "gaming" (changing the attribute(s) to achieve a more favorable target) by increasing footprint under footprint-based standards than by increasing vehicle mass under weight-based standards—it is relatively easy for a manufacturer to add enough weight to a vehicle to decrease its applicable fuel economy target a significant amount, as compared to increasing vehicle footprint. We also continue to agree with concerns raised in 2008 by some commenters on the MY 2011 CAFE rulemaking that there would be greater potential for gaming under multi-attribute standards, such as those that also depend on weight, torque, power, towing capability, and/or off-road capability. The agencies agree with the assessment first presented in NHTSA's MY 2011 CAFE final rule[4] that the possibility of gaming an attribute-based standard is lowest with footprint-based standards, as opposed to weight-based or multi-attribute-based standards. Specifically, standards that incorporate weight, torque, power, towing capability, and/or off-road capability in addition to footprint would not only be more complex, but by providing degrees of freedom with respect to more easily-adjusted attributes, they could make it less certain that the future fleet would actually achieve the average fuel economy and CO_2 reduction levels projected by the agencies.[e] This is not to say that a footprint-based system will eliminate gaming, or that a footprint-based system will eliminate the possibility that manufacturers will change vehicles in ways that compromise occupant protection. In the agencies' judgment, footprint-based standards achieved the best balance among affected considerations.

The agencies recognize that based on economic and consumer demand factors that are external to this rule, the distribution of footprints in the future may be different (either smaller or larger) than what is projected in this rule. However, the agencies continue to believe that there will not be significant shifts in this distribution as a direct consequence of this rule. We note that comments by CBD, ACEEE, and NACAA referenced a 2011 study by Whitefoot and Skerlos, "Design incentives to increase vehicle size created from the U.S. footprint-based fuel economy standards."[f] This study concluded that the proposed MY 2014 standards

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[e]However, for heavy-duty pickups and vans not covered by today's standards, the agencies determined that use of footprint and work factor as attributes for heavy duty pickup and van GHG and fuel consumption standards could reasonably avoid excessive risk of gaming. See 76 FR 57106, 57161-62 (Sept. 15, 2011)
[f] *Available at* Docket ID: EPA-HQ-OAR-2010-0799.

"create an incentive to increase vehicle size except when consumer preference for vehicle size is near its lower bound and preference for acceleration is near its upper bound."[g] The commenters who cited this study generally did so as part of arguments in favor of flatter standards (*i.e.*, curves that are flatter across the range of footprints) for MYs 2017-2025. While the agencies consider the concept of the Whitefoot and Skerlos analysis to have some potential merits, it is also important to note that, among other things, the authors assumed different inputs than the agencies actually used in the MYs 2012-2016 rules regarding the baseline fleet, the cost and efficacy of potential future technologies, and the relationship between vehicle footprint and fuel economy. Were the agencies to use the Whitefoot and Skerlos methodology (*e.g.*, methods to simulate manufacturers' potential decisions to increase vehicle footprint) with the actual inputs to the MYs 2012-2016 rules, the agencies would likely obtain different findings. Underlining the potential uncertainty, considering a range of scenarios, the authors obtained a wide range of results in their analyses. The agencies discuss this study more fully in the Section II of the preamble, the NHTSA RIA, and the EPA response to comments document.

The agencies also recognize that some international attribute-based standards use attributes other than footprint and that there could be benefits for a number of manufacturers if there was greater international harmonization of fuel economy and GHG standards for light-duty vehicles, but this is largely a question of how stringent standards are and how they are tested and enforced. It is entirely possible that footprint-based and weight-based systems can coexist internationally and not present an undue burden for manufacturers if they are carefully crafted. Different countries or regions may find different attributes appropriate for basing standards, depending on the particular challenges they face—from fuel prices, to family size and land use, to safety concerns, to fleet composition and consumer preference, to other environmental challenges besides climate change. The agencies anticipate working more closely with other countries and regions in the future to consider how to address these issues in a way that least burdens manufacturers while respecting each country's need to meet its own particular challenges.

In the proposal, the agencies found that footprint was the most appropriate attribute upon which to base the proposed standards. Recognizing strong public interest in this issue, the agencies sought comment on whether a different attribute or combination of attributes should be considered in setting standards for the final rule. The agencies specifically requested that the commenters address the concerns raised in the proposal regarding the use of other attributes, and explain how standards should be developed using the other attribute(s) in a way that contributes more to fuel savings and CO_2 reductions than the footprint-based standards, without compromising safety.

The agencies received several comments regarding the attribute(s) upon which new CAFE and GHG standards should be based. NADA[h] and the Consumer Federation of

[g] *Ibid.*, page 410
[h] NADA, Docket No. NHTSA-2010-0131-0261, at 11.

America (CFA)[i] expressed support for attribute-based standards, generally, indicating that such standards accommodate consumer preferences, level the playing field between manufacturers, and remove the incentive to push consumers into smaller vehicles. Many commenters, including automobile manufacturers, NGOs, trade associations and parts suppliers (*e.g.*, General Motors,[j] Ford,[k] American Chemistry Council,[l] Alliance of Automobile Manufacturers,[m] International Council on Clean Transportation,[n] Insurance Institute for Highway Safety,[o] Society of the Plastics Industry,[p] Aluminum Association,[q] Motor and Equipment Manufacturers Association,[r] and others) expressed support for the continued use of vehicle footprint as the attribute upon which to base CAFE and CO_2 standards, citing advantages similar to those mentioned by NADA and CFA. Conversely, the Institute for Policy Integrity (IPI) at the New York University School of Law questioned whether non-attribute-based (flat) or an alternative attribute basis would be preferable to footprint-based standards as a means to increase benefits, improve safety, reduce "gaming," and/or equitably distribute compliance obligations.[s] IPI argued that, even under flat standards, credit trading provisions would serve to level the playing field between manufacturers. IPI acknowledged that NHTSA, unlike EPA, is required to promulgate attribute-based standards, and agreed that a footprint-based system could have much less risk of gaming than a weight-based system. IPI suggested that the agencies consider a range of options, including a fuel-based system, and select the approach that maximizes net benefits. Ferrari and BMW suggested that the agencies consider weight-based standards, citing the closer correlation between fuel economy and footprint, and BMW further suggested that weight-based standards might facilitate international harmonization (*i.e.,* between U.S. standards and related standards in other countries).[t] Porsche commented that the footprint attribute is not well suited for manufacturers of high performance vehicles with a small footprint.[u]

Regarding the comments from IPI, as IPI appears to acknowledge, EPCA/EISA expressly requires that CAFE standards be attribute-based and defined in terms of mathematical functions. Also, NHTSA has, in fact, considered and reconsidered options other than footprint, over the course of multiple CAFE rulemakings conducted throughout the past decade. When first contemplating attribute-based systems, NHTSA considered attributes such as weight, "shadow" (overall area), footprint, power, torque, and towing capacity. NHTSA also considered approaches that would combine two or potentially more than two

[i] CFA, Docket No. EPA-HQ-OAR-2010-0799-9419at 8, 44.
[j] GM, Docket No. NHTSA-2010-0131-0236, at 2.
[k] Ford, Docket No. NHTSA-2010-0131-0235, at 8.
[l] ACC, Docket No. EPA-HQ-OAR-2010-0799-9517at 2.
[m] Alliance, Docket No. NHTSA-2010-0131-0262, at 85.
[n] ICCT, Docket No. NHTSA-2010-0131-0258, at 48.
[o] IIHS, Docket No. NHTSA-2010-0131-0222, at 1.
[p] SPI, Docket No. EPA-HQ-OAR-2010-0799-9492, at 4.
[q] Aluminum Association, Docket No. NHTSA-2010-0131-0226, at 1.
[r] MEMA, Docket No. EPA-HQ-OAR-2010-0799-9478], at 1.
[s] IPI, Docket No. EPA-HQ-OAR-2010-0799-11485at 13-15.
[t] BMW, Docket No. NHTSA-2010-0131-0250, at 3.
[u] Porsche, EPA-HQ-OAR-2010-0799-9264

such attributes. To date, every time NHTSA (more recently, with EPA) has reconsidered options, the agency has concluded that a properly designed footprint-based approach provides the best means of achieving the basic policy goals (i.e., better balancing compliance burdens among full-line and limited-line manufacturers and reducing incentives for manufacturers to respond to standards by reducing vehicle size in ways that could compromise overall highway safety) involved in applying an attribute-based standards, and at the same time structuring footprint-based standards in a way that furthers the energy and environmental policy goals of EPCA and the CAA by controlling incentives to increase vehicle size in ways that could increase fuel consumption and GHG emissions.[v] In response to IPI's suggestion to use fuel-based standards as a type of attribute, although neither NHTSA nor EPA have presented quantitative analysis of standards that differentiate between fuel type for light-duty vehicles, such standards would effectively use fuel type to identify different subclasses of vehicles, thus requiring mathematical functions—not addressed by IPI's comments—to recombine these fuel types into regulated classes.[w] Insofar as EPCA/EISA already specifies how different fuel types are to be treated for purposes of calculating fuel economy and CAFE levels, and moreover, insofar as the EISA revisions to EPCA removed NHTSA's previously-clear authority to set separate CAFE standards for different classes of light trucks, using fuel type to further differentiate subclasses of vehicles could conflict with the intent, and possibly the letter, of NHTSA's governing statute. Finally, in the agencies' judgment, while regarding IPI's suggestion that the agencies select the attribute-based approach that maximizes net benefits may have merit, net benefits are but one of many considerations which lead to the setting of the standard. Also, such an undertaking would be impracticable at this time, considering that the mathematical forms applied under each attribute-based approach would also need to be specified, and that the agencies lack methods to reliably quantify the relative potential for induced changes in vehicle attributes.

Regarding Ferrari's and BMW's comments, as stated previously, in the agencies' judgment, footprint-based standards (a) discourage vehicle downsizing that might compromise occupant protection, (b) encourage the application of technology, including weight-efficient materials (*e.g.*, high-strength steel, aluminum, magnesium, composites, *etc.*), and (c) are less susceptible than standards based on other attributes to "gaming" that could lead to less-than-projected energy and environmental benefits. It is also important to note that there are many differences between both the standards and the on-road light-duty vehicle

[v] *See* 71 FR 17566, at17595-17596 (April 6, 2006); 74 FR 14196, at14359 (March 30, 2009); 75 FR 25324 at 25333 (May 7, 2010).

[w] The agencies did adopt separate standards for gasoline and diesel heavy-duty pickups and vans based on technological differences between gasoline and diesel engines. See 76 FR at 57163-65. However, the agencies stated that "standards that do not distinguish between fuel types are generally preferable where technological and market-based reasons do not strongly argue otherwise. These technological differences exist presently between gasoline and diesel engines for GHGs … The agencies emphasize, however, that they are not committed to perpetuating separate GHG standards for gasoline and diesel heavy-duty vehicles and engines, and expect to reexamine the need for separate gasoline/diesel standards in the next rulemaking." 76 FR at 57165. IPI did not suggest that there were any such technological distinctions justifying separate fuel-based attributes for light duty vehicles, and the agencies note that EPCA/EISA already specifies how different fuels are to be treated for purposes of CAFE

fleets in Europe and the United States. The stringency of standards, independent of the attribute used, is another factor that influences harmonization. While the agencies agree that international harmonization of test procedures, calculation methods, and/or standards could be a laudable goal, again, harmonization is not simply a function of the attribute upon which the standards are based. Given the differences in the on-road fleet (including vehicle classification and use), in fuel composition and availability, in regional consumer preferences for different vehicle characteristics, in other vehicle regulations besides for fuel economy/CO_2 emissions, it would not necessarily be expected that the CAFE and GHG emission standards would align with standards of other countries. Thus, the agencies continue to judge vehicle footprint to be a preferable attribute for the same reasons enumerated in the proposal and reiterated above.

Finally, as explained in section III.B.6 and documented in section III.D.6 below, EPA agrees with Porsche that the MY 2017 GHG standards, and the GHG standards for the immediately succeeding model years, pose special challenges of feasibility and (especially) lead time for intermediate volume manufacturers, in particular for limited-line manufacturers of smaller footprint, high performance passenger cars. It is for this reason that EPA has provided additional lead time to these manufacturers. NHTSA, however, is providing no such additional lead time. Under EISA/EPCA, manufacturers continue—as since the 1970s—to have the option of paying civil penalties in lieu of achieving compliance with the standards.

2.3 What mathematical functions have the agencies previously used, and why?

2.3.1 NHTSA in MY 2008 and MY 2011 CAFE (constrained logistic)

For the MY 2011 CAFE rule, NHTSA estimated fuel economy levels after normalization for differences in technology, but did not make adjustments to reflect other vehicle attributes (*e.g.*, power-to-weight ratios).[x] Starting with the technology adjusted passenger car and light truck fleets, NHTSA used minimum absolute deviation (MAD) regression without sales weighting to fit a logistic form as a starting point to develop mathematical functions defining the standards. NHTSA then identified footprints at which to apply minimum and maximum values (rather than letting the standards extend without limit) and transposed these functions vertically (*i.e.*, on a gpm basis, uniformly downward) to produce the promulgated standards. In the preceding rule, for MYs 2008-2011 light truck standards, NHTSA examined a range of potential functional forms, and concluded that, compared to other considered forms, the constrained logistic form provided the expected and appropriate trend (decreasing fuel economy as footprint increases), but avoided creating "kinks" the agency was concerned would provide distortionary incentives for vehicles with neighboring footprints.[y]

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[x] *See* 74 FR 14196, 14363-14370 (Mar. 30, 2009) for NHTSA discussion of curve fitting in the MY 2011 CAFE final rule.

[y] *See* 71 FR 17556, 17609-17613 (Apr. 6, 2006) for NHTSA discussion of "kinks" in the MYs 2008-2011 light truck CAFE final rule (there described as "edge effects"). A "kink," as used here, is a portion of the curve where a small change in footprint results in a disproportionally large change in stringency.

2.3.2 MYs 2012-2016 Light Duty GHG/CAFE (constrained/piecewise linear)

For the MYs 2012-2016 rules, NHTSA and EPA re-evaluated potential methods for specifying mathematical functions to define fuel economy and GHG standards. The agencies concluded that the constrained logistic form, if applied to post-MY 2011 standards, would likely contain a steep mid-section that would provide undue incentive to increase the footprint of midsize passenger cars.[5] The agencies judged that a range of methods to fit the curves would be reasonable, and used a minimum absolute deviation (MAD) regression without sales weighting on a technology-adjusted car and light truck fleet to fit a linear equation. This equation was used as a starting point to develop mathematical functions defining the standards as discussed above. The agencies then identified footprints at which to apply minimum and maximum values (rather than letting the standards extend without limit) and transposed these constrained/piecewise linear functions vertically (*i.e.*, on a gpm or CO_2 basis, uniformly downward) to produce the fleetwide fuel economy and CO_2 emission levels for cars and light trucks described in the final rule.[6]

2.3.3 How have the agencies defined the mathematical functions for the MYs 2017-2025 standards, and why?

By requiring NHTSA to set CAFE standards that are attribute-based and defined by a mathematical function, NHTSA interprets Congress as intending that the post-EISA standards to be data-driven – a mathematical function defining the standards, in order to be "attribute-based," should reflect the observed relationship in the data between the attribute chosen and fuel economy.[z] EPA is also setting attribute-based CO_2 standards defined by similar mathematical functions, for the reasonable technical and policy grounds discussed below and in section II of the preamble to the rule, and to harmonize with the CAFE standards.

The relationship between fuel economy (and GHG emissions) and footprint, though directionally clear (*i.e.*, fuel economy tends to decrease and CO_2 emissions tend to increase with increasing footprint), is theoretically vague and quantitatively uncertain; in other words, not so precise as to *a priori* yield only a single possible curve.[aa] There is thus a range of legitimate options open to the agencies in developing curve shapes. The agencies may of course consider statutory objectives in choosing among the many reasonable alternatives since the statutes do not dictate a particular mathematical function for curve shape. For example, curve shapes that might have some theoretical basis could lead to perverse outcomes contrary

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[z] A mathematical function can be defined, of course, that has nothing to do with the relationship between fuel economy and the chosen attribute – the most basic example is an industry-wide standard defined as the mathematical function *average required fuel economy* = *X*, where *X* is the single mpg level set by the agency. Yet a standard that is simply defined as a mathematical function that is not tied to the attribute(s) would not meet the requirement of EISA.

[aa] In fact, numerous manufacturers have confidentially shared with the agencies what they describe as "physics based" curves, with each OEM showing significantly different shapes, and footprint relationships. The sheer variety of curves shown to the agencies further confirm the lack of an underlying principle of "fundamental physics" driving the relationship between CO_2 emission or fuel consumption and footprint, and the lack of an underlying principle to dictate any outcome of the agencies' establishment of footprint-based standards.

to the intent of the statutes to conserve energy and reduce GHG emissions. .[bb] Thus, the decision of how to set the target curves cannot always be just about most "clearly" using a mathematical function to define the relationship between fuel economy and the attribute; it often has to have reflect legitimate policy judgments, where the agencies adjust the function that would define the relationship in order to achieve environmental goals, reduce petroleum consumption, encourage application of fuel-saving technologies, not adversely affect highway safety, reduce disparities of manufacturers' compliance burdens (thereby increasing the likelihood of improved fuel economy and reduced GHG emissions across the entire spectrum of footprint targets), preserve consumer choice, etc. This is true both for the decisions that guide the mathematical function defining the sloped portion of the target curves, and for the separate decisions that guide the agencies' choice of "cutpoints" (if any) that define the fuel economy/CO_2 levels and footprints at each end of the curves where the curves become flat. Data informs these decisions, but how the agencies define and interpret the relevant data, and then the choice of methodology for fitting a curve to the data, must include a consideration of both technical data and policy goals. Supporting the consideration and selection of mathematical functions upon which to base new CAFE and GHG standards, the agencies conducted a broad-ranging analysis spanning different techniques for adjusting data and fitting linear functions. The next sections examine the policy concerns that the agencies considered in developing the target curves that define the MYs 2017-2025 CAFE and CO_2 standards, technical work (expanding on similar analyses performed by NHTSA when the agency proposed MY 2011-2015 standards, and by both agencies during consideration of options for MY 2012-2016 CAFE and GHG standards) that was completed in the process of reexamining potential mathematical functions for this rulemaking, how the agencies have defined the data, and how the agencies explored statistical curve-fitting methodologies in order to arrive at proposed and final curves. Because the agencies are finalizing the target curves for MYs 2017-2025 as proposed, the following discussion largely mirrors the discussion in the version of the TSD that accompanied the proposal; it is repeated here for the reader's convenience.

2.4 What did the agencies propose for the MYs 2017-2025 curves?

The mathematical functions for the proposed MYs 2017-2025 standards were somewhat changed from the functions for the MYs 2012-2016 standards, in response to comments received from stakeholders both pre-proposal and during the public comment period and in order to address technical concerns and policy goals that the agencies judged more significant in this nine-model year rulemaking than in the prior one, which only included five model years.[cc] This section (2.4) discusses the methodology the agencies

[bb] For example, if the agencies set weight-based standards defined by a steep function, the standards might encourage manufacturers to keep adding weight to their vehicles to obtain less stringent targets.

[cc] We note that although, due to statutory constraints, NHTSA is finalizing standards for only MYs 2017-2021 and presenting augural standards for MYs 2022-2025, the joint analysis was conducted by NHTSA and EPA with respect to shapes of target curves for all nine model years – both because EPA is indeed finalizing all nine years of standard curves, and because NHTSA's augural standards for MYs 2022-2025 represent the agency's

selected as best addressing those technical concerns and policy goals for this rulemaking, given the various technical inputs to the agencies' current analyses. Section 2.5 discusses how the agencies determined the cutpoints and the flat portions of the MYs 2017-2025 target curves. We note that both of these sections address only how the target curves were fit to fuel consumption and CO_2 emission values determined using the city and highway test procedures, and that in determining respective regulatory alternatives, the agencies made further adjustments to the resultant curves in order to account for adjustments for improvements to mobile air conditioners.

Thus, recognizing that there are many reasonable statistical methods for fitting curves to data points that define vehicles in terms of footprint and fuel economy, the agencies chose for the proposed rule to fit curves using an ordinary least-squares formulation, on sales-weighted data, using a fleet that has had technology applied, and after adjusting the data for the effects of weight-to-footprint, as described below. This represents a departure from the statistical approach for fitting the curves in the MYs 2012-2016 rules, as explained in the next section (2.4.1). The agencies considered a wide variety of reasonable statistical methods in order to better understand the range of uncertainty regarding the relationship between fuel consumption (the inverse of fuel economy), CO_2 emission rates, and footprint, thereby providing a range within which decisions about standards would be potentially supportable.

2.4.1 What concerns were the agencies looking to address that led them to change from the approach used for the MYs 2012-2016 curves?

Before the MY 2017 and later proposal was issued, NHTSA and EPA received a number of comments from stakeholders on how curves should be fitted to the passenger car and light truck fleets.[dd] Some limited-line manufacturers argued that curves should generally be flatter in order to avoid discouraging production of small vehicles, because steeper curves tend to result in more stringent targets for smaller vehicles. Most full-line manufacturers argued that a passenger car curve similar in slope to the MY 2016 passenger car curve would be appropriate for future model years, but that the light truck curve should be revised to be less stringent for manufacturers selling the largest full-size pickup trucks. These manufacturers argued that the MY 2016 light truck curve was not "physics-based," and that in order for future tightening of standards to be feasible for full-line manufacturers, the truck curve for later model years should be steeper and extended further (i.e., made less stringent) into the larger footprints. As stated in the TSD accompanying the proposal, the agencies do not agree that the MY 2016 light truck curve was somehow deficient in lacking a "physics basis," or that it was somehow overly stringent for manufacturers selling large pickups—manufacturers making these arguments presented no "physics-based" model to explain how fuel economy should depend on footprint.[ee] The same manufacturers indicated that they

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best estimate, based on the information currently before it, of the standards that the agency would finalize had it the authority to do so. NHTSA will fully revisit all aspects of the MYs 2022-2025 standards as part of the later rulemaking concurrent with the mid-term evaluation.

[dd] See 75 FR at 76341 for a general summary.

[ee] See footnote **Error! Bookmark not defined.**.

believed that the light truck standard should be somewhat steeper after MY 2016, primarily because, after more than ten years of progressive increases in the stringency of applicable CAFE standards, large pickups would be less capable of achieving further improvements without compromising load carrying and towing capacity.

In developing the curve shapes for the proposed rule, the agencies were aware of the current and prior technical concerns raised by OEMs concerning the effects of the stringency on individual manufacturers and their ability to meet the standards with available technologies, while producing vehicles at a cost that allowed them to recover the additional costs of the technologies being applied. Although we continue to believe that the methodology for fitting curves for the MYs 2012-2016 standards was technically sound, we recognize manufacturers' technical concerns regarding their abilities to comply with a similarly shallow curve after MY 2016 given the anticipated mix of light trucks in MYs 2017-2025. As in the MYs 2012-2016 rules, the agencies considered these concerns in the analysis of potential curve shapes for the MYs 2017-2025 proposal. The agencies also considered safety concerns which could be raised by curve shapes creating an incentive for vehicle downsizing, as well as the potential loss to consumer welfare should vehicle upsizing be unduly disincentivized. In addition, the agencies sought to improve the balance of compliance burdens among manufacturers, and thereby increase the likelihood of improved fuel economy and reduced GHG emissions across the entire spectrum of footprint targets. Among the technical concerns and resultant policy trade-offs the agencies considered were the following:

- Flatter standards (*i.e.*, curves) increase the risk that both the weight and size of vehicles will be reduced, potentially compromising highway safety.
- Flatter standards potentially impact the utility of vehicles by providing an incentive for vehicle downsizing.
- Steeper footprint-based standards may create incentives to upsize vehicles, thus increasing the possibility that fuel economy and greenhouse gas reduction benefits will be less than expected.
- Given the same industry-wide average required fuel economy or CO_2 standard, flatter standards tend to place greater compliance burdens on full-line manufacturers
- Given the same industry-wide average required fuel economy or CO_2 standard, steeper standards tend to place greater compliance burdens on limited-line manufacturers (depending of course, on which vehicles are being produced).
- If cutpoints are adopted, given the same industry-wide average required fuel economy, moving small-vehicle cutpoints to the left (*i.e.*, up in terms of fuel economy, down in terms of CO_2 emissions) discourages the introduction of small vehicles, and reduces the incentive to downsize small vehicles in ways that could compromise overall highway safety.
- If cutpoints are adopted, given the same industry-wide average required fuel economy, moving large-vehicle cutpoints to the right (*i.e.*, down in terms of fuel economy, up in terms of CO_2 emissions) better accommodates the design requirements of larger vehicles—especially large pickups—and extends the size range over which downsizing is discouraged.

All of these were policy goals that required weighing and consideration. Ultimately, the agencies rejected the argument that the MY 2017 target curves for the proposal, on a relative basis, should be made significantly flatter than the MY 2016 curve,[ff] as we believed that this would undo some of the safety-related incentives and balancing of compliance burdens among manufacturers—effects that attribute-based standards are intended to provide.

Nonetheless, the agencies recognized full-line OEM concerns and tentatively concluded that further increases in the stringency of the light truck standards would be more feasible if the light truck curve is made steeper than the MY 2016 truck curve and the right (large footprint) cut-point is extended over time to larger footprints. This conclusion was supported by the agencies' technical analyses of regulatory alternatives defined using the curves developed in the manner described below.

2.4.2 What methodologies and data did the agencies consider in developing the 2017-2025 curves presented in the proposal?

In considering how to address the various policy concerns discussed in the previous sections, the agencies revisited the data and performed a number of analyses using different combinations of the various statistical methods, weighting schemes, adjustments to the data and the addition of technologies to make the fleets less technologically heterogeneous. As discussed in 2.3.3, in the agencies' judgment, there is no single "correct" way to estimate the relationship between CO_2 or fuel consumption and footprint – rather, each statistical result is based on the underlying assumptions about the particular functional form, weightings and error structures embodied in the representational approach. These assumptions are the subject of the following discussion. This process of performing many analyses using combinations of statistical methods generated many possible outcomes, each embodying different potentially reasonable combinations of assumptions and each thus reflective of the data as viewed through a particular lens. The choice of a standard developed by a given combination of these statistical methods was consequently a decision based upon the agencies' determination of how, given the policy objectives for this rulemaking and the agencies' MY 2008-based forecast of the market through MY 2025, to appropriately reflect the current understanding of the evolution of automotive technology and costs, the future prospects for the vehicle market, and thereby establish curves (i.e., standards) for cars and light trucks.

2.4.2.1 For the MYs 2017-2025 standards, what information did the agencies use to estimate a relationship between fuel economy, CO2 and footprint?

For each fleet, the agencies began with the MY 2008-based market forecast developed to support the proposal (*i.e.*, the baseline fleet), with vehicles' fuel economy levels and technological characteristics at MY 2008 levels.[gg] The development, scope, and content of

[ff] While "significantly" flatter is subjective qualitative description, the year over year change in curve shapes is discussed in greater detail in Section 2.5.3.1.

[gg] While the agencies jointly conducted this analysis, the coefficients ultimately used in the slope setting analysis are from the CAFE model.

this market forecast is discussed in detail in Chapter 1 of the joint Technical Support Document supporting the proposed rulemaking.

Figure 2-1 shows the MY 2008 CO_2 by car and truck class as it existed in the EPA OMEGA and NHTSA CAFE NPRM model data files (for a gasoline-only fleet, fuel consumption—the inverse of fuel economy—is directly proportional to CO_2). This fleet was the starting point for all analysis in the proposal.

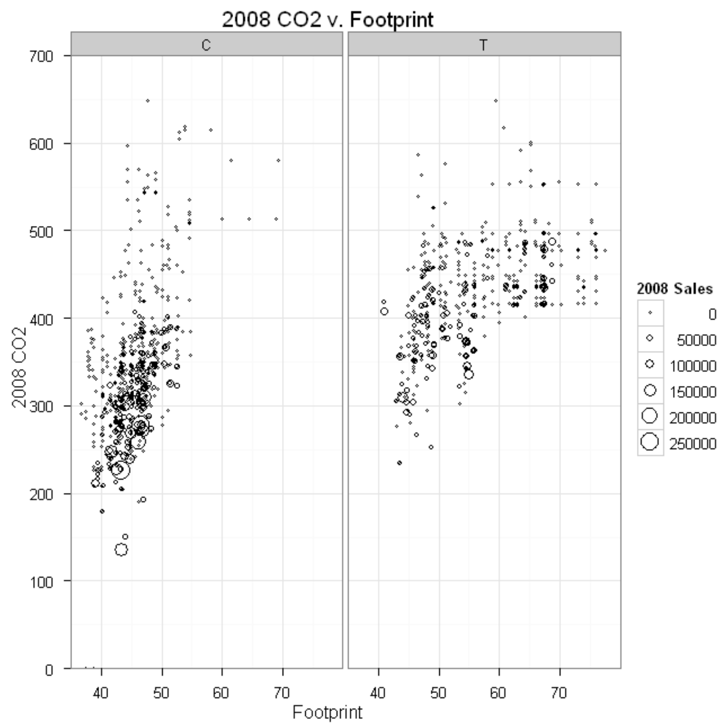

Figure 2-1 2008 CO2 vs. Footprint by Car and Truck

Although the agencies are finalizing the target curves as proposed, the agencies have also revisited and updated their analyses for this final rule, and found that the proposed curves are well within the ranges spanned by the final rule analyses. See section 2.6 below. As discussed in Chapter 1 of this TSD, the agencies have used two different market forecasts to conduct additional analyses supporting this final rule. The first, referred to here as the "MY 2008-Based Fleet Projection," is largely identical to that used for analysis supporting the NPRM, but includes some corrections to the footprint of some vehicle models discussed in Chapter 1, as well as other minor changes. The second, referred to here as the "MY 2010-Based Fleet Projection," is a post-proposal market forecast based on the MY 2010 fleet of vehicles. Using both of these projected fleets, the agencies repeated the analyses described below, and obtained broadly similar results, details of which are presented in a memorandum available in NHTSA's docket.[hh] Because the agencies are promulgating target curve standards identical to those proposed in the NPRM, the remainder of this chapter reviews results supporting the development of those proposed standards. This chapter concludes with a summary of results of the agencies' updated analysis, and discussion of the consideration that analysis was given in selecting mathematical functions upon which to base the standards in the final rules.

2.4.2.2 What adjustments did the agencies evaluate?

As indicated in the TSD supporting the NPRM, one possible approach is to fit curves to the minimally adjusted data shown above (the approach still includes sales mix adjustments, which influence results of sales-weighted regressions), much as DOT did when it first began evaluating potential attribute-based standards in 2003.[7] However, the agencies found, as in prior rulemakings, that the data are so widely spread (*i.e.*, when graphed, they fall in a loose "cloud" rather than tightly around an obvious line) that they indicate a relationship between footprint and CO_2 and fuel consumption that is real but not particularly strong (Figure 2-1). Therefore, as discussed below, the agencies also explored possible adjustments that could help to explain and/or reduce the ambiguity of this relationship, or could help to produce policy outcomes the agencies judged to be more desirable.

2.4.2.3 Adjustment to reflect differences in technology

As in prior rulemakings, the agencies considered technology differences between vehicle models to be a significant factor producing uncertainty regarding the relationship between CO_2/fuel consumption and footprint. Noting that attribute-based standards are intended to encourage the application of additional technology to improve fuel efficiency and reduce CO_2 emissions, the agencies, in addition to considering approaches based on the unadjusted engineering characteristics of MY 2008 vehicle models, therefore also considered approaches in which, as for previous rulemakings, technology is added to vehicles for purposes of the curve fitting analysis in order to produce fleets that are less varied in technology content. This approach helps to reduce "noise" (*i.e.*, dispersion) in the plot of vehicle footprints and fuel consumption levels and to identify a more technology-neutral relationship between footprint and fuel economy / CO_2 emissions.

For the analysis supporting the NPRM, the agencies adjusted the NPRM baseline fleet for technology by adding all technologies considered, except for, diesel engines, integrated starter generators, strong HEVs, PHEVs, EVs, FCVs, and the most advanced high-BMEP (brake

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[hh] Docket No. NHTSA-2010-0131. As with the NPRM analysis, EPA and NHTSA jointly analyzed the fleet projections used in this final rulemaking. While the proposal and final rulemaking analyses shown in this chapter are from the NHTSA CAFE model, the EPA OMEGA results are generally similar, and support the same conclusions. A memo containing the OMEGA results for the FRM can be found in EPA docket EPA-HQ-OAR-2010-0799.

mean effective pressure) gasoline engines.[ii] The agencies included 15 percent mass reduction on all vehicles. Figure 2-2 shows the same fleet, with technology adjustment and 2021 sales applied, and the baseline diesel fueled vehicles, HEV and EVs removed from the fleet. Of note, the fleet is now more closely clustered[jj] (and lower in emissions), but the same basic pattern emerges; in both figures, the CO_2 emission rate (which, as mentioned above, is directly proportional to fuel consumption for a gasoline-only fleet) increases with increasing footprint, although the relationship is less pronounced for larger light trucks.

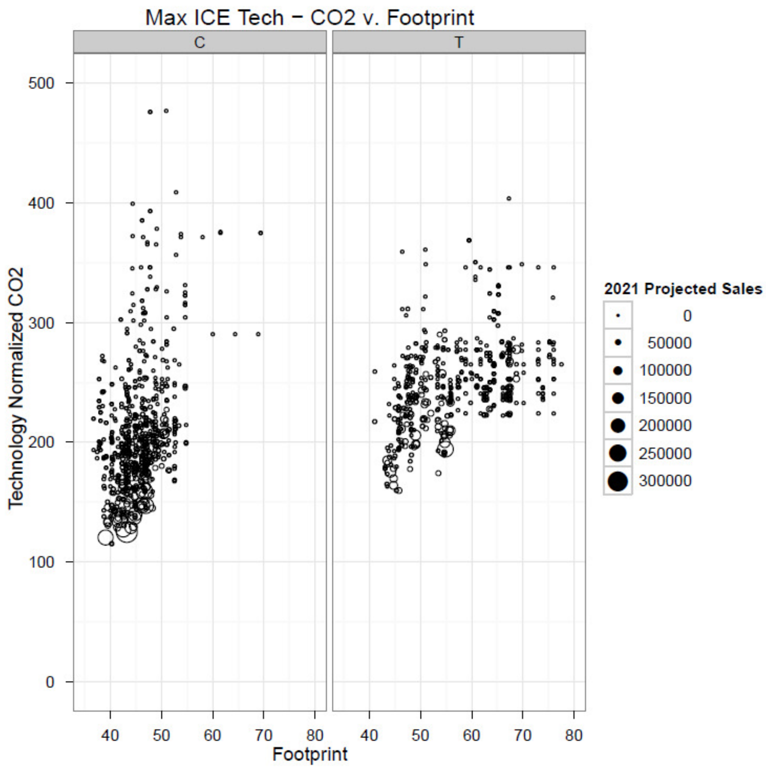

Figure 2-2 2008 CO2 vs. Footprint by Car and Truck, after Adjustment Reflecting Technology Differences, and removing diesel fueled vehicles, HEVs and EVs

Updating this analysis using the current MY2008- and MY2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with

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[ii] As described in the preceding paragraph, applying technology in this manner serves to reduce the effect of technology differences across the vehicle fleet. The particular technologies used for the normalization were chosen as a reasonable selection of technologies which could potentially be used by manufacturer over this time period.

[jj] For cars, the standard deviation of the CO_2 data is reduced from 81 to 54 through the technology normalization. For trucks, the standard deviation is reduced from 62 to 36.

the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[kk]

2.4.2.4 Adjustments reflecting differences in performance and "density"

As discussed in Section 2.4.1, during stakeholder meetings the agencies held while developing the NPRM,[ll] some manufacturers indicated that they believed that the light truck standard should be somewhat steeper after MY 2016. As a means to produce a steeper light truck curve, the agencies considered adjustments for other differences between vehicle models (*i.e.*, inflating or deflating the fuel economy of each vehicle model based on the extent to which one of the vehicle's attributes, such as power, is higher or lower than average). Previously, NHTSA had rejected such adjustments because they imply that a multi-attribute standard may be necessary, and as explained above, the agencies judged most multi-attribute standards to be more subject to gaming than a footprint-only standard.[mm,8] Having considered this issue again for purposes of this rulemaking, NHTSA and EPA concluded the need to accommodate in the target curves the challenges faced by manufacturers of large pickups currently outweighs these prior concerns (comments on this topic are discussed in Section 0 and 2.4.2.11 and in Section II.C of the preamble). Therefore, the agencies also evaluated curve fitting approaches through which fuel consumption and CO_2 levels were adjusted with respect to weight-to-footprint alone, and in combination with power-to-weight. While the agencies examined these adjustments for purposes of fitting curves, the agencies did not propose a multi-attribute standard; the proposed fuel economy and CO_2 targets for each vehicle were still functions of footprint alone. The agencies are not promulgating a multi-attribute standard, and no adjustment will be used in the compliance process.

The agencies also examined some differences between the technology-adjusted car and truck fleets in order to better understand the relationship between footprint and CO_2/fuel consumption in the agencies' MY 2008 based forecast. More direct measures (such as coefficients of drag and rolling resistance), while useful for vehicle simulation, were not practical or readily available at the fleet level. Given this issue, and based on analysis published in the MYs 2012-2016 rule,[9] the agencies investigated a sales-weighted (*i.e.*, treating every vehicle unit sold as a separate observation) regression equation involving power to weight ratio and vehicle weight (Equation 2-1).[nn] This equation provides for a

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[kk] Docket No. NHTSA-2010-0131.

[ll] See Preamble I.A.2 for a discussion of the stakeholder meetings before the NPRM.

[mm] For example, in comments on NHTSA's 2008 NPRM regarding MY 2011-2015 CAFE standards, Porsche recommended that standards be defined in terms of a "Summed Weighted Attribute", wherein the fuel economy target would calculated as follows: $target = f(SWA)$, where *target* is the fuel economy target applicable to a given vehicle model and $SWA = footprint + torque^{1/1.5} + weight^{1/2.5}$. (NHTSA-2008-0089-0174). While the standards the agencies proposed for MY 2017-2025 are not multi-attribute standards, that is the target is only a function of footprint, we proposed curve shapes that were developed considering more than one attribute.

[nn] These parameters directly relate to the amount of energy required to move the vehicle. As compared to a lighter vehicle, more energy is required to move a heavier vehicle the same distance. Similarly, a more powerful engine, when technology adjusted, is less efficient than a less powerful engine.

strong correlation between HP/WT, weight and CO_2 emissions (R^2=0.78, Table 2-1) after accounting for technology adjustments.[oo]

Equation 2-1 – Relationship between vehicle attributes and emissions or fuel consumption

$$\mathrm{CO2i\ or\ GPMi} = \beta_{hp/wt}\left(\frac{\mathrm{Horsepower}}{\mathrm{Weight}}\right)_i + \beta_{weight}\mathrm{Weight}_i + C$$

Where:

HP/Weight= the rated horsepower of the vehicle divided by the curb weight
Weight = the curb weight of the vehicle in pounds
C = a constant.

Table 2-1 – Physical Regression Coefficients against Technology Adjusted CO_2[*]

	Cars	Light Trucks
R^2	0.78	0.78
F-test p	<0.01	<0.01
$\beta_{hp/wt}$	$1.09*10^3$	$1.13*10^3$
β_{weight}	$3.29*10^{-2}$	$3.45*10^{-2}$
C	-3.29	2.73

*In this gasoline only fleet, these coefficients can be divided by 8887 (the amount of CO2 produced by the combustion of a gallon of the fuel used to certify the fuel economy and emissions of gasoline vehicles) to yield the corresponding fuel consumption coefficients.

Updating this analysis using the MY 2008- and MY 2010-based fleet projections yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[pp]

The coefficients above show, for the agencies' MY 2008-based market forecast as developed for the NPRM, strong correlation between these vehicle attributes and the fuel consumption and emissions of the vehicle, as well as strong similarity between car and truck coefficients. (As explained in section 2.6 below, our analysis using the corrected version of the MY 2008 based market forecast used for the final rule, as well as the alternative 2010 based market forecast, is consistent with these results.) Given these very similar parameters,

[oo] As R^2 does not equal 1, there are remaining unaccounted for differences beyond technology, power and weight. These may include gear ratios, axle ratios, aerodynamics, and other vehicle features not captured in this equation.

[pp] Docket No. NHTSA-2010-0131.

similar distributions of power and weight would be expected to produce similarly arrayed plots of CO_2 (or equivalently, fuel consumption) by footprint, regardless of car or truck class. Based on the differences seen in the technology-adjusted plot (Figure 2-2), the agencies further investigated these particular attributes and their relationship to footprint in the agencies' MY 2008-based market forecast developed for the NPRM, to examine the differences across the footprint distribution.

Figure 2-3 shows vehicle curb weight charted against footprint, with sales weighted ordinary least squares sales fit (blue) and sales-weighted LOESS fit (red) imposed. For cars, the LOESS fit, which weights nearby points more heavily, [qq] is nearly identical to the linear fit in the data filled region between about 40 and 56 sq ft (with the gray bar showing standard error on the Loess fit). For this market forecast, average car curb weight is linearly proportional to car footprint between 40 and 56 sq ft, or in other words, cars progress in weight in a regular fashion as they get larger (Figure 2-3).

Figure 2-3 By contrast, a linear fit does not overlap with the LOESS fit on the truck side, which indicates that for this market forecast, truck curb weight does not linearly increase with footprint, at least not across the entire truck fleet. The LOESS fit shows that larger trucks (those on the right side of the data bend in Figure 2-2) have a different trend than smaller trucks, and after about 55 sq ft, no longer proportionally increases in weight. The same pattern is seen in Figure 2-1 and Figure 2-2 above.

[qq]: In a LOESS regression, "fitting is done locally. That is, for the fit at point *x*, the fit is made using points in a neighborhood of *x*, weighted by their distance from *x* (with differences in 'parametric' variables being ignored when computing the distance). The size of the neighborhood is controlled by α For $\alpha < 1$, the neighborhood includes proportion α of the points, and these have tricubic weighting (proportional to *(1 - (dist/maxdist)^3)^3*. For $\alpha > 1$, all points are used, with the 'maximum distance' assumed to be *α^1/p* times the actual maximum distance for *p* explanatory variables."
A span of 1 was used in these images. http://cran.r-project.org/doc/manuals/fullrefman.pdf, p. 1406.

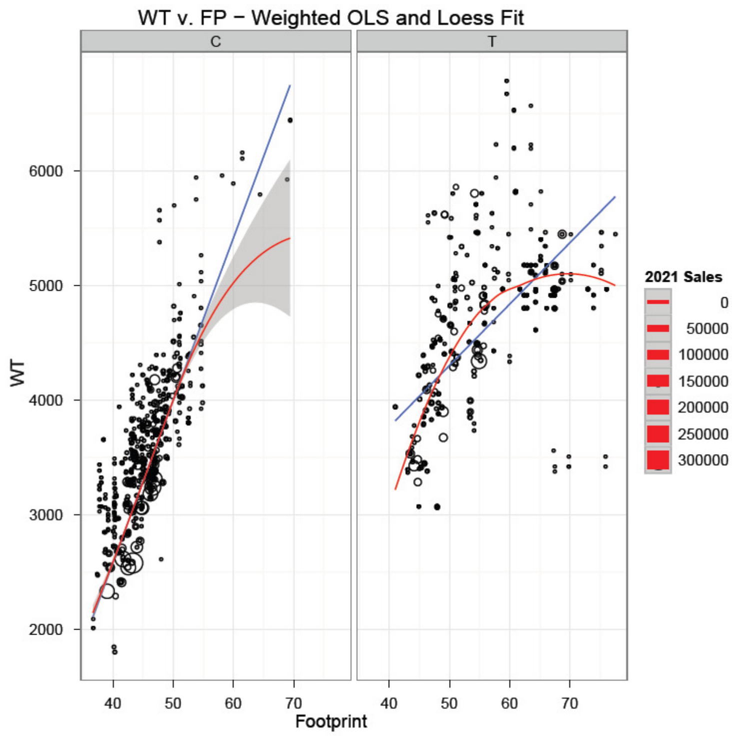

Figure 2-3 Relationship between Weight and Footprint in Agencies' MY2008-Based Market Forecast

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[rr]

To further pursue this topic, weight divided by footprint (WT/FP) can be thought of as a "density" of a vehicle (although dimensionally it has units of pressure). As seen in Figure 2-4, the trend in WT/FP in the agencies' MY2008-based market forecast is different in trucks than in cars. The linear trend on cars is an increase in WT/FP as footprint increases (Figure 2-4). In contrast, light trucks do not consistently increase in WT/FP ratio as the vehicles grow larger, but WT/FP actually decreases (Figure 2-4).

[rr] Docket No. NHTSA-2010-0131.

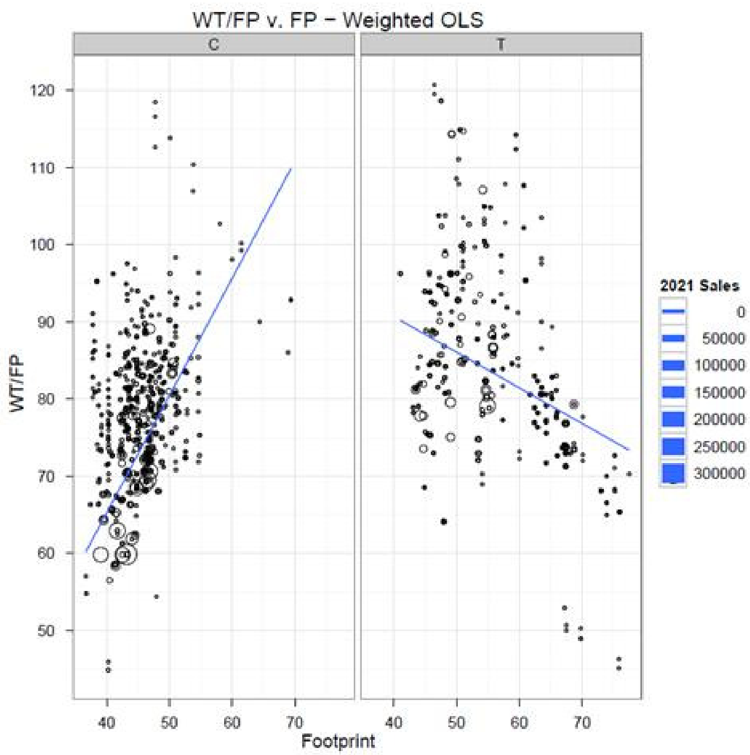

Figure 2-4 Relationship between Weight/FP and Footprint in Agencies' MY2008-Based Market Forecast

Updating this analysis using the current MY 2008- and MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[ss]

The heterogeneity of the truck fleet explains part of the WT/FP trend, where the pickup truck fleet is largest in footprint, but is also relatively light for its size due to the flat bed (Figure 2-5). Note that the two light truck classes with the smallest WT/FP ratios are small and large pickups. Further, as the only vehicle class with a sales-weighted average footprint above 60 square feet, the large pickup trucks have a strong influence on the slope of the truck curve. As the correlation between weight and CO_2 is strong (Table 2-1), having proportionally lighter vehicles at one extreme of the footprint distribution can bias a curve fit to these vehicles. If no adjustment is made to the curve fitted to the truck fleet, and no other compensating flexibilities or adjustments are made available, manufacturers selling significant numbers of vehicles at the large end of the truck distribution will face compliance burdens that are comparatively more challenging that those faced by manufacturers not serving this part of the light truck market. As noted further below, this consideration

[ss] Docket No. NHTSA-2010-0131.

provided the basis for the agencies' proposal to change the cutpoint for larger light trucks from 66 feet to 74 feet, and to steepen the slope of the light truck curve for larger light trucks.

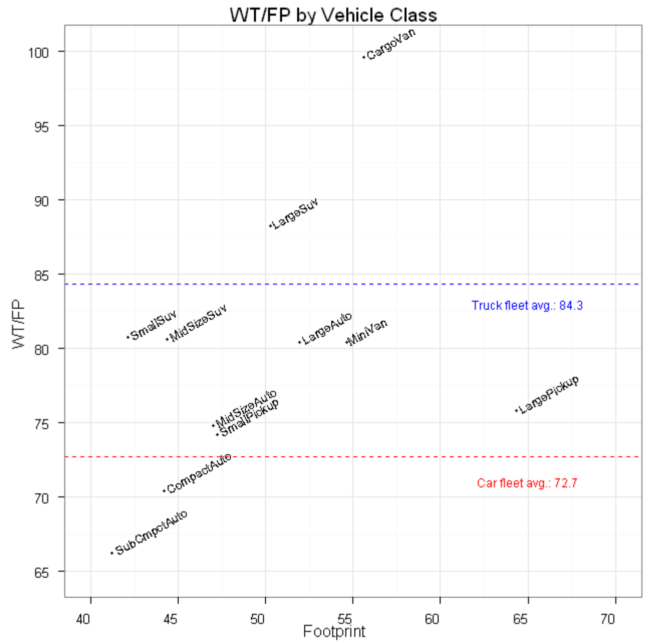

Figure 2-5 Class and the WT/FP distribution

Updating this analysis using the revised MY 2008- and the MY 2010-based market forecasts yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[tt]

The agencies also investigated the relationship between HP/WT and footprint in the agencies' MY 2008-based market forecast developed for the NPRM (Figure 2-6). On a sales weighted basis, cars tend to become proportionally more powerful as they get larger. In contrast, there is a minimally positive relationship between HP/WT and footprint for light trucks, indicating that light trucks become only slightly more powerful as they get larger, but that the trend is not especially pronounced.

[tt] Docket No. NHTSA-2010-0131.

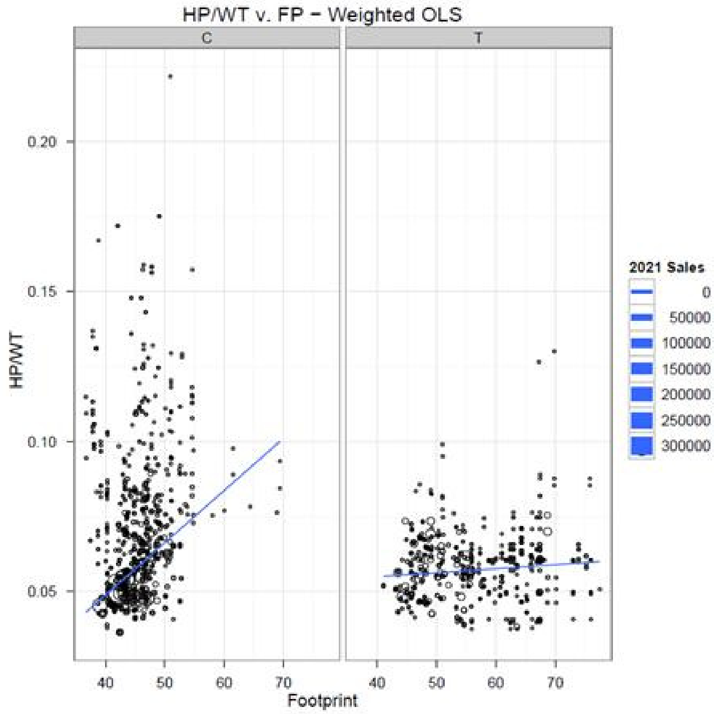

Figure 2-6 HP/WT v. FP

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[uu]

One factor influencing results of this analysis is the non-homogenous nature of the truck fleet; some vehicles at the smaller end of the footprint curve are different in design and utility from others at the larger end (leading to the observed bend in the LOESS fit, Figure 2-6). There are many high volume four-wheel drive vehicles with smaller footprint in the truck fleet (such as the Chevrolet Equinox, Dodge Nitro, Ford Escape, Honda CR-V, Hyundai Santa Fe, Jeep Liberty, Nissan Rogue, Toyota RAV4, and others) exhibit only select truck characteristics.[vv] By contrast, the largest pickup trucks in the light truck fleet have unique aerodynamic and power characteristics that tend to increase CO_2 emissions and fuel consumption. These disparities contribute to the slopes of lines fitted to the light truck fleet.

[uu] Docket No. NHTSA-2010-0131.

[vv] In most cases, these vehicles have four-wheel drive, but no significant towing capability, and no open-bed. Many of these vehicles are also offered without four-wheel drive, and these two-wheel drive versions are classified as passenger cars, not light trucks.

Several comments, such as those by CBD and ACEEE, were submitted with regard to the non-homogenous nature of the truck fleet, and the "unique" attributes of pickup trucks. Ford Motor Company described the attributes of these vehicles, noting that "towing capability generally requires increased aerodynamic drag caused by a modified frontal area, increased rolling resistance, and a heavier frame and suspension to support this additional capability."[ww] Ford further noted that these vehicles further require auxiliary transmission oil coolers, upgraded radiators, trailer hitch connectors and wiring harness equipment, different steering ratios, upgraded rear bumpers and different springs for heavier tongue load (for upgraded towing packages), body-on-frame (vs. unibody) construction (also known as ladder frame construction) to support this capability and an aggressive duty cycle, and lower axle ratios for better pulling power/capability. In the agencies' judgment, the curves and cutpoints defining the light truck standards appropriately account for engineering differences between different types of vehicles. For example, the agencies' estimates of the applicability, cost, and efficacy of different fuel-saving technologies differentiate between small, medium, and large light trucks. Further discussion on this topic is contained in Section II.C.

The agencies' technical analyses of regulatory alternatives developed using curves fitted as described below supported OEM comments that there would be significant compliance challenges for the manufacturers of large pickup trucks, and led toward the agencies' policy goal of a steeper slope for the light truck curve relative to MY 2016. Three primary drivers were as follows: (a) the largest trucks have unique equipment and design, as described in the Ford comment referenced above; (b) the agencies agree with those large truck manufacturers who indicated in discussions prior to the proposal that they believed that the light truck standard should be somewhat steeper after MY 2016, primarily because, after more than ten recent years of progressive increases in the stringency of applicable CAFE standards (after nearly ten years during which Congress did not allow NHTSA to increase light truck CAFE standards), manufacturers of large pickups would have limited options to comply with more stringent standards without resorting to compromising large truck load carrying and towing capacity; and (c) given the relatively few platforms which comprise the majority of the sales at the largest truck footprints, the agencies were concerned about requiring levels of average light truck performance that might lead to overly aggressive advanced technology penetration rates in this important segment of the work fleet. Specifically, the agencies were concerned at proposal, and remain concerned, about issues of lead time and cost with regard to manufacturers of these work vehicles. As noted later in this chapter, while the largest trucks are a small segment of the overall truck fleet, and an even smaller segment of the overall fleet, [xx] these changes to the truck slope have been made in order to provide a clearer path toward compliance for manufacturers of these vehicles, and reduce the potential that new

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[ww] Ford comments, Docket No. [fill in], at [page number].

[xx] The agencies' market forecast used at proposal includes about 24 vehicle configurations above 74 square feet with a total volume of about 50,000 vehicles or less during any MY in the 2017-2025 time frame, In the MY2010 based market forecast, there are 14 vehicle configurations with a total volume of 130,000 vehicles or less during any MY in the 2017-2025 time frame. This is a similarly small portion of the overall number of vehicle models or vehicle sales.

standards would lead these manufacturers to choose to downpower, modify the structure, or otherwise reduce the utility of these work vehicles.

Some commenters disagreed with these policy goals concerning the largest light trucks and argued that higher fuel economy for the largest light trucks is fully compatible with maintaining towing and hauling capacity. These comments, which largely deal with stringency, are addressed in each agency's respective preamble section (III.D and IV.F), as well as in Section II.C, which addresses the shapes of the target curves. Consequently, the agencies considered options including fitting curves developed using results of the analysis described above. Specifically, the agencies note that the WT/FP ratio of the light duty fleet potentially has a large impact on a sales-weighted regression.[yy] The increasing trend in WT/FP versus footprint for cars in the 2008 MY baseline would steepen the slope of the car curve, while the decreasing trend in WT/FP would flatten the truck slope, as compared to a WT/FP adjusted fleet. This result was reflected in the MYs 2012-2016 final rulemaking,[10] where the agencies noted the steep car curves resulting from a weighted least-squares analysis.

Based on the above analysis, the agencies also considered adjustments for other differences between vehicle models. Therefore, utilizing the coefficients derived in Equation 2-1, the agencies also evaluated curve fitting approaches through which fuel consumption and CO_2 levels were adjusted with respect to weight-to-footprint alone, and in combination with power-to-weight. This adjustment procedure inflates or deflates the fuel economy or CO_2 emissions of each vehicle model based on the extent to which one of the vehicle's attributes, such as power, is higher or lower than average. As mentioned above, while the agencies considered this technique for purposes of fitting curves, the agencies did not propose a multi-attribute standard, as the proposed fuel economy and CO_2 targets for each vehicle were still functions of footprint alone. The agencies are not promulgating a multi-attribute standard, and no adjustment would be used in the compliance process.

The basis for the gallon-per-mile (GPM) adjustments is the sales-weighted linear regression discussed in 2.4 (Equation 2-1, Table 2-1). The coefficients to this equation give the impact of the various car attributes on CO_2 emissions and fuel consumption in the agencies' MY 2008-based market forecast used in the NPRM. For example, β_{weight} gives the impact of weight while holding the ratio horsepower to weight constant. Importantly, this means that as weight changes, horsepower must change as well to keep the power/weight ratio constant. Similarly, $\beta_{hp/wt}$ gives the CO_2 impact of changing the performance of the vehicle while keeping the weight constant. These coefficients were used to perform an adjustment of the gallons per mile measure for each vehicle to the respective car or truck—*i.e.,* in the case of a HP/WT adjustment, to deflate or inflate the fuel consumption of each vehicle model based on the extent to which the vehicle's power-to-weight ratio is above or below the regression-based value at that footprint.

[yy] As mentioned above, the agencies also performed the same analysis without sales-weighting, and found that the WT/FP ratio also had a directionally similar effect on the fitted car and truck curves.

The agencies performed this normalization to adjust for differences in vehicle weight per square foot observations in the data discussed in Section 2.4. This adjustment process requires two pieces of information: the weight coefficient from Equation 2-1 and the average weight per footprint (*i.e.*, pounds per square foot) for that vehicle's group. Two groups, passenger cars and light trucks, were used. For each group, the average weight per footprint was calculated as a weighted average with the weight being the same as in the above regression (projected sales by vehicle in 2021). The equation below indicates how this adjustment was carried out.

Equation 2-2 WT/FP adjustment

$$\text{Weight per Footprint Adjusted GPM}_i \text{ or CO2i} = \text{GPM}_i - \left(\text{Weight}_i - \frac{\overline{\text{Weight}}}{\text{Footprint}} \times \text{Footprint}_i\right) \times \beta_{\text{weight}}$$

The term in parentheses represents the vehicle's deviation from an "expected weight." That is, multiplying the average weight per footprint for a group of vehicles (cars or trucks) by a specific vehicle's footprint gives an estimate of the weight of that specific vehicle if its density were "average," based on the analyzed fleet. Put another way, this factor represents what the weight is "expected" to be, given the vehicle's footprint, and based on the analyzed fleet. This "expected weight" is then subtracted from the vehicle's actual weight. Vehicles that are heavier than their "expected weight" will receive a positive value (*i.e.*, a deflated fuel economy value) here, while vehicles that are lighter than their "expected weight" will receive a negative number (*i.e.*, an inflated fuel economy value).

This deviation from "expected weight" is then converted to a gallon value by the regression coefficient. The units on this coefficient are gallons per mile per pound, as can be deduced from equation 1. This value is then subtracted from the vehicle's actual gallons per mile measure. Note that the adjusted truck data no longer exhibits the bend seen in Figure 2-1 and Figure 2-2.

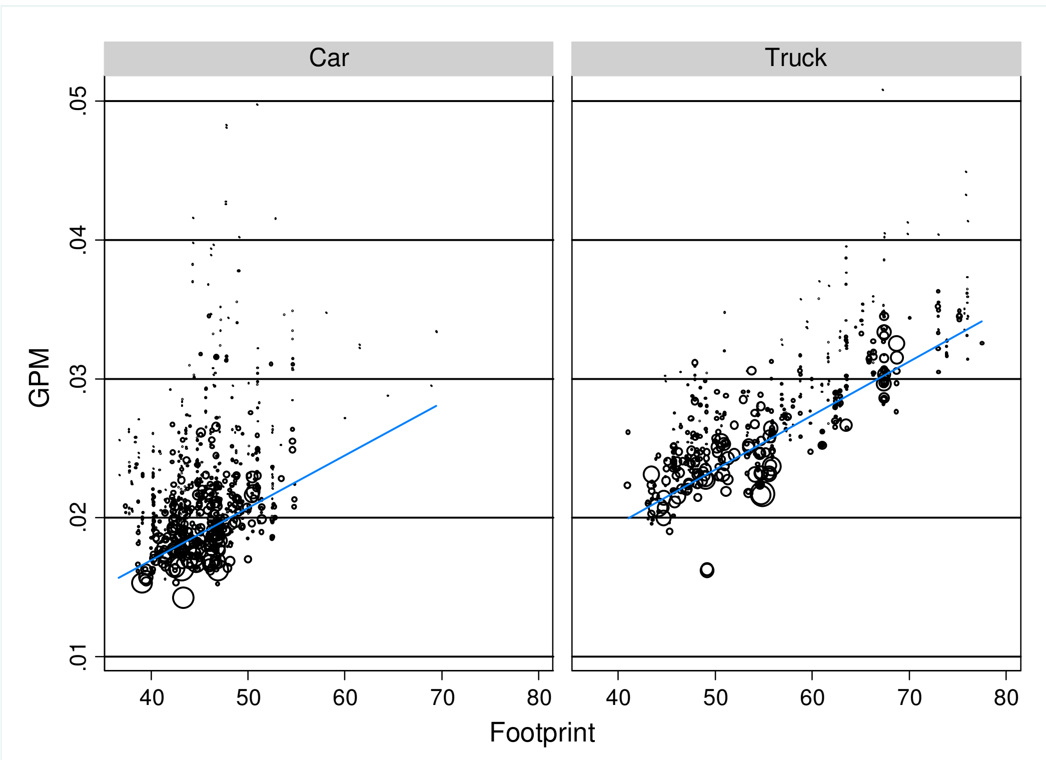

Figure 2-7 WT/FP Adjusted Fuel Consumption vs. Footprint

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[zz]

This adjustment serves to reduce the variation in gallons per mile measures caused by variation in weight in the agencies' MY 2008-based market forecast used in the NPRM. Importantly, this adjustment serves to reduce the fuel consumption (*i.e.*, inflate fuel economy) for those vehicles which are heavier than their footprint would suggest while increasing the gallons per mile measure (*i.e.*, deflating fuel economy) for those vehicles which are lighter. For trucks, a linear trend is more evident in the data cloud.[aaa] The following table shows the degree of adjustment for several vehicle models:

[zz] Docket No. NHTSA-2010-0131.

[aaa] Using EPA's dataset, R^2 for the sales weighted ordinary least squared linear fit between footprint and CO_2 improved from 0.38 (technology adjusted CO_2) to 0.64 (technology and weight / footprint adjusted CO_2)

Table 2-2 - Sample Adjustments for Weight to Footprint, Cars

Manufacturer	Model	Name Plate	Weight / Footprint	Footprint	GPM	MPG	Adjusted GPM	Adjusted MPG	GPM % Adjustment
HONDA	HONDA FIT	FIT	64.4	39.5	0.01	69.40	0.0157	63.73	8.9%
TOYOTA	TOYOTA COROLLA	COROLLA	61.3	42.5	0.01	69.94	0.0164	60.80	15.0%
FORD	FORD FOCUS	FOCUS FWD	62.9	41.7	0.02	61.94	0.0177	56.34	9.9%
GENERAL MOTORS	CHEVROLET MALIBU	MALIBU	73.5	46.9	0.02	53.70	0.0185	54.08	-0.7%
HONDA	HONDA ACCORD	ACCORD 4DR SEDAN	69.6	46.6	0.02	57.57	0.0179	55.73	3.3%
NISSAN	INFINITI G37	G37 COUPE	76.7	47.6	0.02	47.83	0.0200	50.08	-4.5%
GENERAL MOTORS	CHEVROLET CORVETTE	CORVETTE	69.3	46.3	0.02	40.84	0.0251	39.83	2.5%
FORD	FORD MUSTANG	MUSTANG	74.7	46.7	0.03	31.32	0.0316	31.67	-1.1%
TOYOTA	TOYOTA CAMRY	CAMRY SOLARA CONVERTIBLE	75.6	46.9	0.02	50.87	0.0191	52.27	-2.7%
VOLKSWAGEN	VOLKSWAGEN JETTA	JETTA	78.0	42.4	0.02	46.77	0.0211	47.47	-1.5%
FORD	FORD FUSION	FUSION FWD	72.2	46.1	0.02	59.96	0.0168	59.61	0.6%
HONDA	HONDA ACCORD	ACCORD 2DR COUPE	71.6	46.6	0.02	56.92	0.0178	56.26	1.2%
HYUNDAI	HYUNDAI SONATA	SONATA	70.7	46.0	0.02	61.72	0.0166	60.34	2.3%
HONDA	HONDA CIVIC	CIVIC	59.9	43.2	0.02	64.25	0.0177	56.38	14.0%

Table 2-3 – Sample Adjustments for Weight to Footprint, Trucks

Manufacturer	Model	Name Plate	Weight / Footprint	Footprint	GPM	MPG	Adjusted GPM	Adjusted MPG	GPM % Adjustment
FORD	FORD ESCAPE	ESCAPE FWD	80.1	65.2	0.02	51.00	0.0181	55.11	-7.5%
GENERAL MOTORS	CHEVROLET C15	C15 SILVERADO 2WD 119WB	85.9	55.9	0.03	39.76	0.0248	40.29	-1.3%
FIAT	JEEP GRAND CHEROKEE	GRAND CHEROKEE 4WD	103.7	47.1	0.02	41.45	0.0222	44.98	-7.9%
HONDA	HONDA PILOT	PILOT 4WD	85.2	51.3	0.02	40.95	0.0243	41.22	-0.6%
TOYOTA	TOYOTA HIGHLANDER	HIGHLANDER 4WD	79.6	49.0	0.02	45.90	0.0227	44.05	4.2%
FORD	FORD F150	F150 FFV 4WD 145 WB	73.8	67.4	0.03	32.70	0.0334	29.97	9.1%
FIAT	DODGE RAM	RAM 1500 PICKUP 4WD 140 WB	78.1	66.3	0.03	33.75	0.0316	31.65	6.6%
TOYOTA	TUNDRA	TOYOTA TUNDRA 4WD 145 WB	79.3	68.7	0.03	32.07	0.0325	30.73	4.3%
TATA	LAND ROVER RANGE ROVER SPORT	RANGE ROVER SPORT	118.6	47.5	0.03	33.17	0.0239	41.92	-20.9%
GENERAL MOTORS	CHEVROLET UPLANDER	UPLANDER FWD	114.4	49.2	0.02	45.46	0.0163	61.34	-25.9%
GENERAL MOTORS	HUMMER H3	H3 4WD	99.9	50.7	0.03	36.71	0.0242	41.30	-11.1%
GENERAL MOTORS	PONTIAC TORRENT	TORRENT FWD	84.2	48.2	0.02	46.64	0.0215	46.56	0.2%
TOYOTA	TACOMA	TOYOTA TACOMA 4WD	74.8	53.4	0.02	43.01	0.0252	39.63	8.5%

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[bbb]

Based on Equation 2-1, the agencies also evaluated an adjustment of GPM and CO_2 based on HP/WT.

Equation 2-3 –Adjustment based on HP/WT

$$\frac{\mathrm{HP}}{\mathrm{WT}}\text{adjusted } \mathrm{GPM_i} \text{ or } \mathrm{CO2_i} = \mathrm{GPM_i} - \left(\frac{\mathrm{HP_i}}{\mathrm{WT_i}} - \overline{\frac{\mathrm{HP}}{\mathrm{WT}}}\right) \times \beta_{\mathrm{HP/WT}}$$

[bbb] Docket No. NHTSA-2010-0131.

Figure 2-8 shows the adjusted data and the estimated relationship between the adjusted GPM values and footprint.

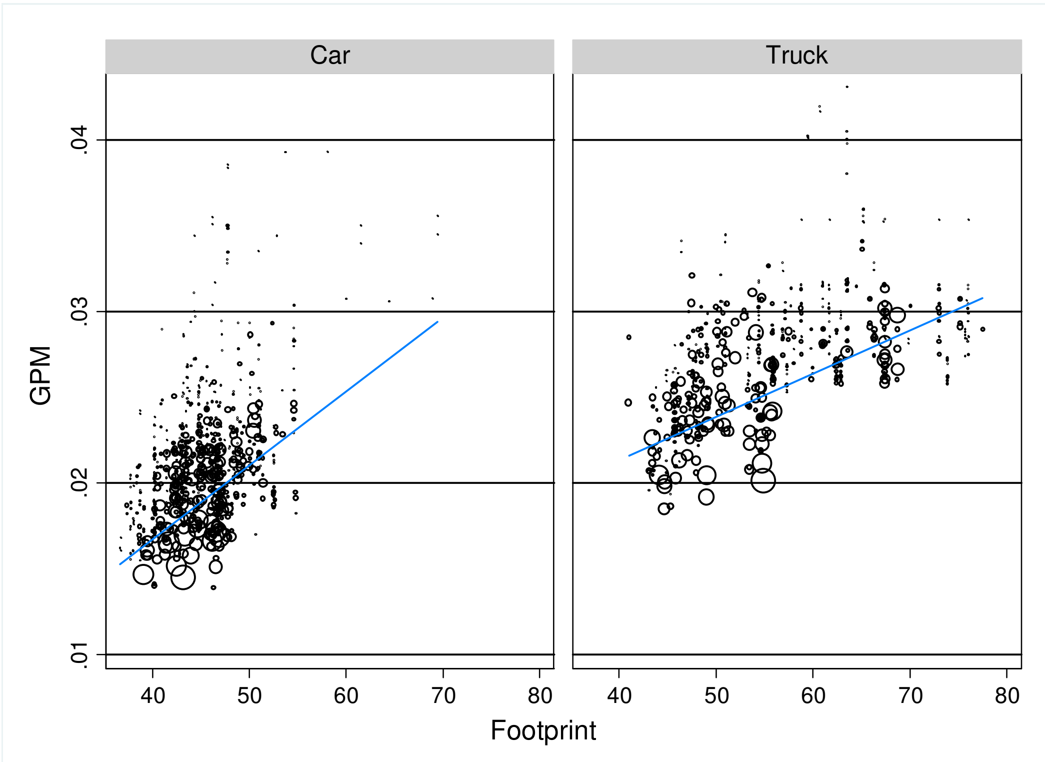

Figure 2-8 HP/WT Adjusted Fuel Consumption v. Footprint

Table 2-4 shows the degree of adjustment for several vehicle models. Those vehicles which have more power than average for their actual curb weight are adjusted downward (*i.e.*, fuel economy ratings are inflated), while those that have less power than average are adjusted upward (*i.e.*, fuel economy ratings are deflated).

Table 2-4 - Sample Adjustments for Horsepower to Weight, Cars

Manufacturer	Model	Name Plate	Horsepower	Footprint	GPM	MPG	Adjusted GPM	Adjusted MPG	GPM % Adjustment
HONDA	HONDA FIT	FIT	109	39.5	0.01	69.40	0.0157	63.73	8.9%
TOYOTA	TOYOTA COROLLA	COROLLA	126	42.5	0.01	69.94	0.0164	60.80	15.0%
FORD	FORD FOCUS	FOCUS FWD	140	41.7	0.02	61.94	0.0177	56.34	9.9%
GENERAL MOTORS	CHEVROLET MALIBU	MALIBU	169	46.9	0.02	53.70	0.0185	54.08	-0.7%

HONDA	HONDA ACCORD	ACCORD 4DR SEDAN	190	46.6	0.02	57.57	0.0179	55.73	3.3%
NISSAN	INFINITI G37	G37 COUPE	330	47.6	0.02	47.83	0.0200	50.08	-4.5%
GENERAL MOTORS	CHEVROLET CORVETTE	CORVETTE	400	46.3	0.02	40.84	0.0251	39.83	2.5%
FORD	FORD MUSTANG	MUSTANG	500	46.7	0.03	31.32	0.0316	31.67	-1.1%
TOYOTA	TOYOTA CAMRY	CAMRY SOLARA CONVERTIBLE	225	46.9	0.02	50.87	0.0191	52.27	-2.7%
VOLKSWAGEN	VOLKSWAGEN JETTA	JETTA	170	42.4	0.02	46.77	0.0211	47.47	-1.5%
FORD	FORD FUSION	FUSION FWD	160	46.1	0.02	59.96	0.0168	59.61	0.6%
HONDA	HONDA ACCORD	ACCORD 2DR COUPE	190	46.6	0.02	56.92	0.0178	56.26	1.2%
HYUNDAI	HYUNDAI SONATA	SONATA	162	46.0	0.02	61.72	0.0166	60.34	2.3%
HONDA	HONDA CIVIC	CIVIC	140	43.2	0.02	64.25	0.0177	56.38	14.0%

Table 2-5 - Sample Adjustments for Horsepower to Weight, Trucks

Manufacturer	Model	Name Plate	Horsepower	Footprint	GPM	MPG	Adjusted GPM	Adjusted MPG	GPM % Adjustment
FORD	FORD ESCAPE	ESCAPE FWD	153	65.2	0.02	51.00	0.0181	55.11	-7.5%
GENERAL MOTORS	CHEVROLET C15	C15 SILVERADO 2WD 119WB	195	55.9	0.03	39.76	0.0248	40.29	-1.3%
FIAT	JEEP GRAND CHEROKEE	GRAND CHEROKEE 4WD	210	47.1	0.02	41.45	0.0222	44.98	-7.9%
HONDA	HONDA PILOT	PILOT 4WD	244	51.3	0.02	40.95	0.0243	41.22	-0.6%
TOYOTA	TOYOTA HIGHLANDER	HIGHLANDER 4WD	270	49.0	0.02	45.90	0.0227	44.05	4.2%
FORD	FORD F150	F150 FFV 4WD 145 WB	300	67.4	0.03	32.70	0.0334	29.97	9.1%
FIAT	DODGE RAM	RAM 1500 PICKUP 4WD 140 WB	345	66.3	0.03	33.75	0.0316	31.65	6.6%
TOYOTA	TUNDRA	TOYOTA TUNDRA 4WD 145 WB	381	68.7	0.03	32.07	0.0325	30.73	4.3%
TATA	LAND ROVER RANGE ROVER SPORT	RANGE ROVER SPORT	300	47.5	0.03	33.17	0.0239	41.92	-20.9%
GENERAL MOTORS	CHEVROLET UPLANDER	UPLANDER FWD	240	49.2	0.02	45.46	0.0163	61.34	-25.9%
GENERAL MOTORS	HUMMER H3	H3 4WD	242	50.7	0.03	36.71	0.0242	41.30	-11.1%
GENERAL MOTORS	PONTIAC TORRENT	TORRENT FWD	185	48.2	0.02	46.64	0.0215	46.56	0.2%
TOYOTA	TACOMA	TOYOTA TACOMA 4WD	236	53.4	0.02	43.01	0.0252	39.63	8.5%

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses are with the final rulemaking fleet projections presented in a memorandum available in NHTSA's docket.[ccc]

The above approaches resulted in three data sets each for (a) vehicles without added technology and (b) vehicles with technology added to reduce technology differences, any of which may provide a reasonable basis for fitting mathematical functions upon which to base the slope of the standard curves: (1) vehicles without any further adjustments; (2) vehicles with adjustments reflecting differences in "density" (weight/footprint); and (3) vehicles with adjustments reflecting differences in "density," and adjustments reflecting differences in performance (power/weight). Further, these sets were developed for both the revised MY 2008-based fleet projection and the post-proposal MY 2010-based fleet projection. Detailed results using these market forecasts are presented in a memorandum available in NHTSA's docket.[ddd]

2.4.2.5 What statistical methods did the agencies evaluate?

Using these data sets, the agencies tested a range of regression methodologies, each judged to be possibly reasonable for application to at least some of these data sets.

2.4.2.6 Regression Approach

In the MYs 2012-2016 final rules, the agencies employed a robust regression approach (minimum absolute deviation, or MAD), rather than an ordinary least squares (OLS) regression.[11] MAD is generally applied to mitigate the effect of outliers in a dataset, and thus was employed in that rulemaking as part of our interest in attempting to best represent the underlying technology. NHTSA had used OLS in early development of attribute-based CAFE standards, but NHTSA (and then NHTSA and EPA) subsequently chose MAD instead of OLS for both the MY 2011 and the MYs 2012-2016 rulemakings. These decisions on regression technique were made both because OLS gives additional emphasis to outliers[12] and because the MAD approach helped achieve the agencies' policy goals with regard to curve slope in those rulemakings.[13] In the interest of taking a fresh look at appropriate regression methodologies as promised in the 2012-2016 light duty rulemaking, in developing this proposal, the agencies gave full consideration to both OLS and MAD. The OLS representation, as described, uses squared errors, while MAD employs absolute errors and thus weights outliers less.

As noted, one of the reasons stated for choosing MAD over least square regression in the MYs 2012-2016 rulemaking was that MAD reduced the weight placed on outliers in the data. As seen in Figure 2-1, there clearly are some outliers in the data, mostly to the high CO_2 and fuel consumption side. However, the agencies have further considered whether it is appropriate to classify these vehicles as outliers. Unlike in traditional datasets, these vehicles' performance is not mischaracterized due to errors in their measurement, a common reason for

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[ccc] Docket No. NHTSA-2010-0131.
[ddd] Docket No. NHTSA-2010-0131.

outlier classification. Being certification data, the chances of large measurement errors should be near zero, particularly towards high CO_2 or fuel consumption. Thus, they can only be outliers in the sense that the vehicle designs are unlike those of other vehicles. These outlier vehicles may include performance vehicles, vehicles with high ground clearance, 4WD, or boxy designs. Given that these are equally legitimate on-road vehicle designs, the agencies concluded that it would appropriate to reconsider the treatment of these vehicles in the regression techniques.

Based on these considerations as well as on the adjustments discussed above, the agencies concluded it was not meaningful to run MAD regressions on gpm data that had already been adjusted in the manner described above. Normalizing already reduced the variation in the data, and brought outliers towards average values. This was the intended effect, so the agencies deemed it unnecessary to apply an additional remedy to resolve an issue that had already been addressed, but we sought comment on the use of robust regression techniques under such circumstances. One commenter, ACEEE, addressed this question in this rulemaking, indicating (consistent with the agencies' views) that MAD and OLS are both technically sound methods for fitting functions.

2.4.2.7 Sales Weighting

Likewise, in the proposal, the agencies reconsidered the application of sales-weighting to represent the data. As explained below, the decision to sales weight or not is ultimately based upon a choice about how to represent the data, and not by an underlying statistical concern. Sales weighting is used if the decision is made to treat each (mass produced) unit sold as a unique physical observation. Doing so thereby changes the extent to which different vehicle model types are emphasized as compared to a non-sales weighted regression. For example, while total General Motors Silverado (332,000) and Ford F-150 (322,000) sales differed by less than 10,000 in MY 2021 market forecast used for the NPRM, 62 F-150s models and 38 Silverado models were reported in the agencies baselines. Without sales-weighting, the F-150 models, because there were more of them, were given 63 percent more weight in the regression despite comprising a similar portion of the marketplace and a relatively homogenous set of vehicle technologies.

The agencies did not use sales weighting in the MYs 2012-2016 rulemaking analysis of the curve shapes. A decision to not perform sales weighting reflects judgment that each vehicle model provides an equal amount of information concerning the underlying relationship between footprint and fuel economy. Sales-weighted regression gives the highest sales vehicle model types vastly more emphasis than the lowest-sales vehicle model types thus driving the regression toward the sales-weighted fleet norm. For unweighted regression, vehicle sales do not matter. The agencies note that the light truck market forecast shows MY 2025 sales of 218,000 units for Toyota's 2WD Sienna, and shows 66 model configurations with MY 2025 sales of fewer than 100 units. Similarly, the agencies' market forecast shows MY 2025 sales of 267,000 for the Toyota Prius, and shows 40 model configurations with MY2025 sales of fewer than 100 units. Sales-weighted analysis would give the Toyota Sienna and Prius more than a thousand times the consideration of many vehicle model configurations. Sales-weighted analysis would, therefore, cause a large number of vehicle model configurations to be virtually ignored in the regressions.[14]

However, the agencies did note in the MYs 2012-2016 final rules that, "sales weighted regression would allow the difference between other vehicle attributes to be reflected in the analysis, and also would reflect consumer demand." [15] In reexamining the sales-weighting for this analysis, the agencies note that there are low-volume model types that account for many of the passenger car model types (50 percent of passenger car model types account for 3.3 percent of sales), and it is unclear whether the engineering characteristics of these model types should equally determine the standard for the remainder of the market.

In the interest of taking a fresh look at appropriate methodologies as promised in the last final rule, in developing proposed and final standards for MYs 2017-2025, the agencies gave full consideration to both sales-weighted and unweighted regressions.

2.4.2.8 Analyses Performed

We performed regressions describing the relationship between a vehicle's CO_2/fuel consumption and its footprint, in terms of various combinations of factors: initial (raw) fleets with no technology, versus after technology is applied; sales-weighted versus non-sales weighted; and with and without two sets of normalizing factors applied to the observations. The agencies excluded diesels and dedicated AFVs because the agencies anticipate that advanced gasoline-fueled vehicles are likely to be dominant through MY2025.

Results supporting development of the proposed and finalized standards are depicted graphically in Figures 2-9 through 2-16, below.

Thus, the basic OLS regression on the initial data (with no technology applied) and no sales-weighting represents one perspective on the relation between footprint and fuel economy. Adding sales weighting changes the interpretation to include the influence of sales volumes, and thus steps away from representing vehicle technology alone. Likewise, MAD is an attempt to reduce the impact of outliers, but reducing the impact of outliers might perhaps be less representative of technical relationships between the variables, although that relationship may change over time in reality. Each combination of methods and data reflects a perspective, and the regression results reflect that perspective in a simple quantifiable manner, expressed as the coefficients determining the line through the average (for OLS) or the median (for MAD) of the data. It is left to policy makers to determine an appropriate perspective and to interpret the consequences of the various alternatives.

The agencies sought comment on the application of the weights as described above, and the implications for interpreting the relationship between fuel efficiency and footprint. ACEEE questioned adjustment of the light truck data based on differences in weight/footprint, indicating that, in their view, the adjustment produces too steep a slope and potentially implies overstatement of the efficacy of some technologies as applied to pickup trucks. ACEEE also suggested that adjustment based on differences in power/weight would yield flatter curves and be more consistent with how the EU constructed related CO_2 targets. The Alliance, in contrast, supported the weightings applied by the agencies, and the resultant relationships between fuel efficiency and footprint. Both ACEEE and the Alliance commented that the agencies should revisit the application of weights—and broader aspects of analysis to develop mathematical functions—in the future. Moreover, although ACEEE expressed concern regarding the outcomes of the application of the weight/footprint adjustment, the agencies maintain that the adjustments (including no adjustments) considered in the NPRM are all potentially reasonable to apply for purposes of developing fuel economy and GHG target curves. This issue is discussed in greater detail in Section II.C of the preamble, and related issues–the slope and stringency of the light truck standards—are addressed further in Sections III and IV of the preamble.

2.4.2.9 What results did the agencies obtain?

Both agencies employed the same statistical approaches. For regressions against data including technology normalization, NHTSA used the CAFE modeling system, and EPA used EPA's OMEGA model. The agencies obtained similar regression results, and based the joint proposal on those obtained by NHTSA.

For illustrative purposes, the set of figures below show the range of curves determined by the possible combinations of regression techniques, with and without sales weighting, with and without the application of technology, and with various adjustments to the gpm variable prior to running a regression. Again, from a statistical perspective, each of these regressions simply represents the assumptions employed. Since they are all univariate linear regressions, they describe the line that will result from minimizing the sum of the residuals (for MAD) or sum of squared residuals (for OLS). Figures show the results for passenger cars, then light trucks, for ordinary least squares (OLS) then similar results for MAD regressions for cars and light trucks, respectively. The various equations are represented by the string of attributes used to define the regression. See the table, Regression Descriptors, below, for the legend. Thus, for example, the line representing "ols_LT_wt_ft_adj_init_w" should be read as follows: an OLS regression, for light trucks, using data adjusted according to weight to footprint, no technology added, and weighted by sales.

Table 2-6 Regression Descriptors

Notation	Description
ols or mad	Ordinary least squares or mean absolute deviation
PC or LT	Passenger car or light truck
hp_wt_adj	Adjustment for horsepower to weight
wt_ft_adj	Adjustment for weight to footprint
wt_ft_hp_wt_adj	Adjustment for both horsepower to weight and weight to footprint
init or final	Vehicles with no technology (initial) or with technology added (final)
u or w	Unweighted or weighted by sales

Thus, the next figures, for example, represent a family of curves (lines) fit using ordinary least squares on data for passenger cars, not modified for technology, and which therefore permits comparisons of results in terms of the factors that change in each regression. These factors are whether the data are sales-weighted (denoted "w") or unweighted (denoted "u"), as well as the adjustments described above. Each of these adjustments has an influence on the regressions results, depicted in the figures below.

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. See section 2.6 below. Detailed results of the analysis with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[eee]

[eee] Docket No. NHTSA-2010-0131.

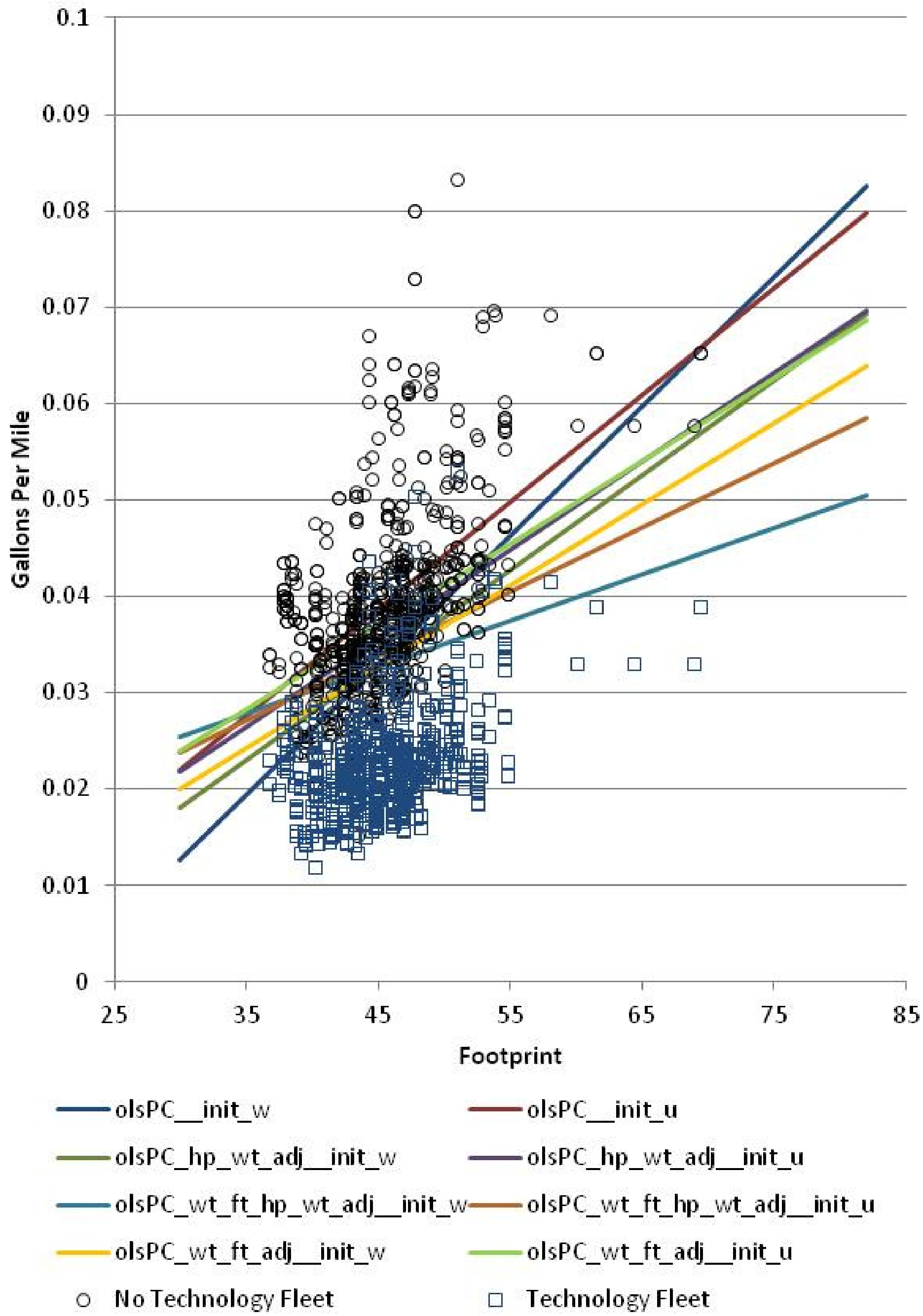

Figure 2-9 Best Fit Results for Various Regressions: Cars, No Added Technology, OLS

Figure 2-10, below, shows comparable results, this time with data representing the additional technology that has been added to reduce technological heterogeneity. Note that the data now pass through the relevant data "cloud" for the fleet with the technology adjustment applied. The slopes of the lines are somewhat more clustered (less divergent) in the chart depicting added technology (as discussed in footnote ii)

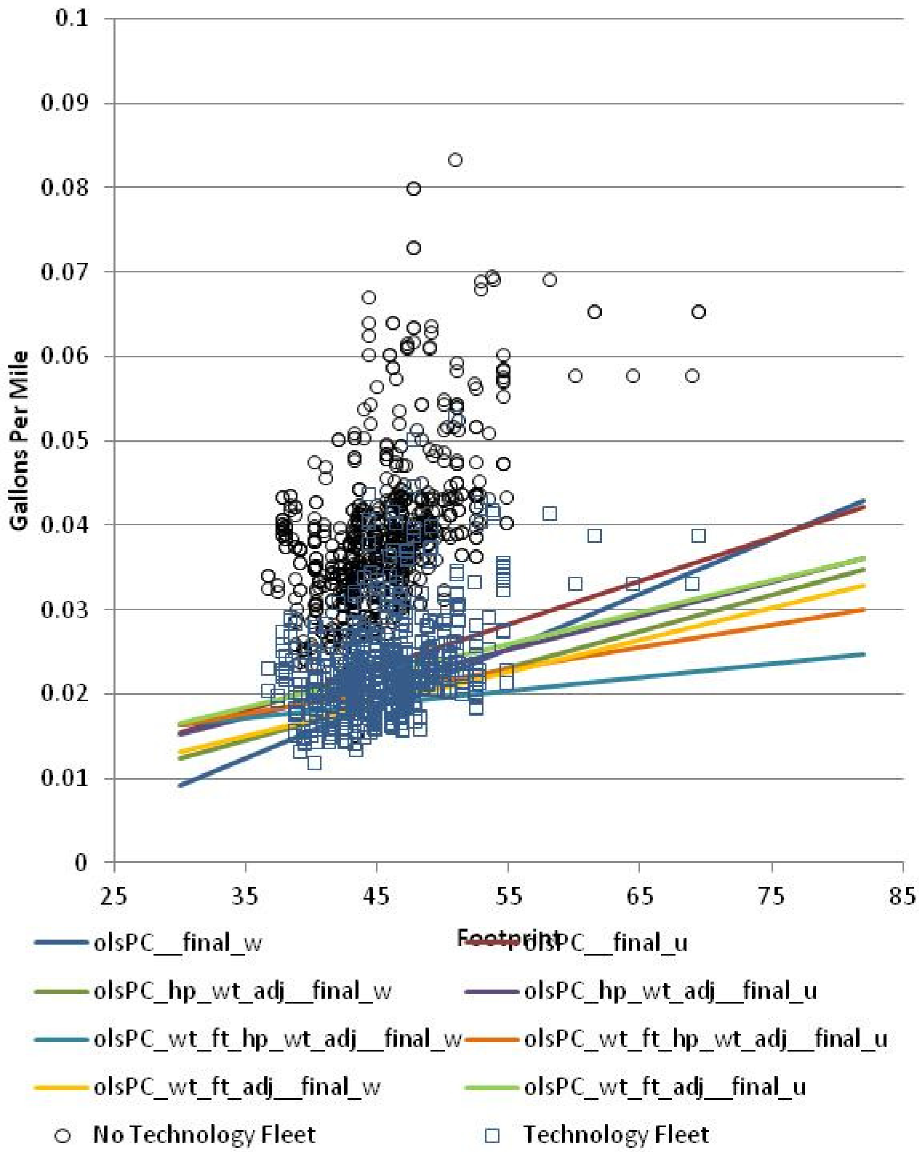

Figure 2-10 Best Fit Results for Various Regressions: Cars, with Added Technology, OLS

Similar to the figures displaying the results for passenger cars, the figures below display regression lines for trucks, first with no technology added, then subsequently, for the case where technology has been added. Slopes appear more similar to each other here than of passenger cars.

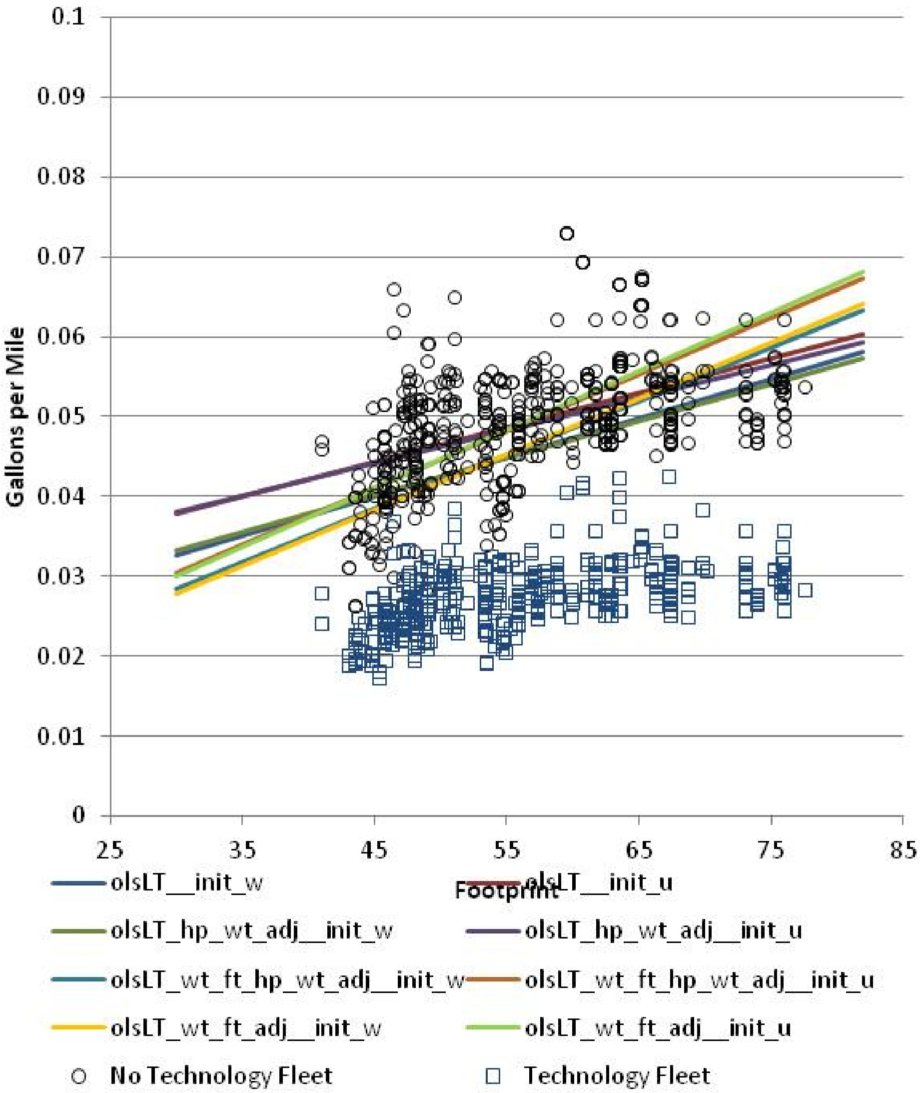

Figure 2-11 Best Fit Results for Various Regressions: Trucks, No Added Technology, OLS

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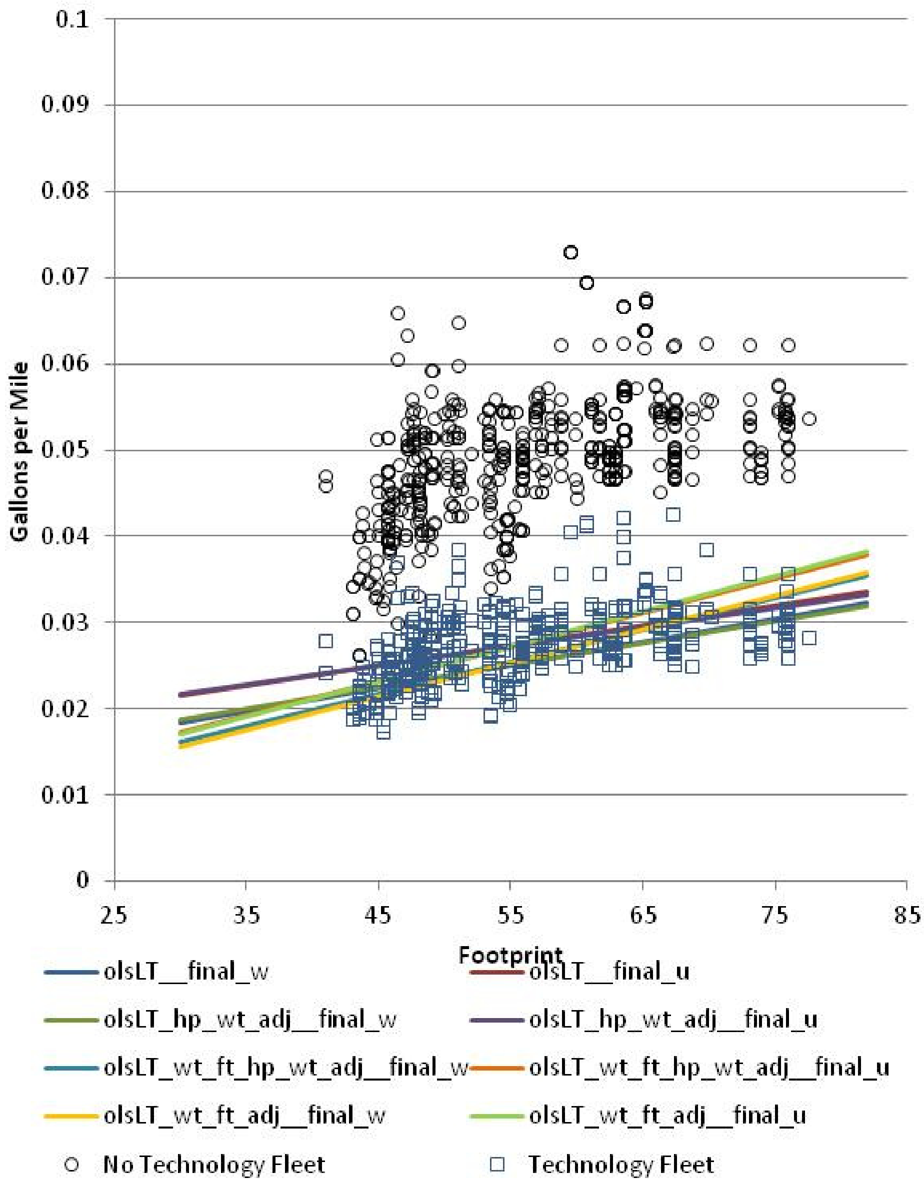

Figure 2-12 Best Fit Results for Various Regressions: Trucks, With Added Technology, OLS

Figure 2-13, below, displays regression results for the passenger car MAD fitted curves. The technology adjustment does not have, however, the same degree of impact in reducing the difference in the attained slopes (between those with and without the addition of technology) evidenced in the OLS regressions.

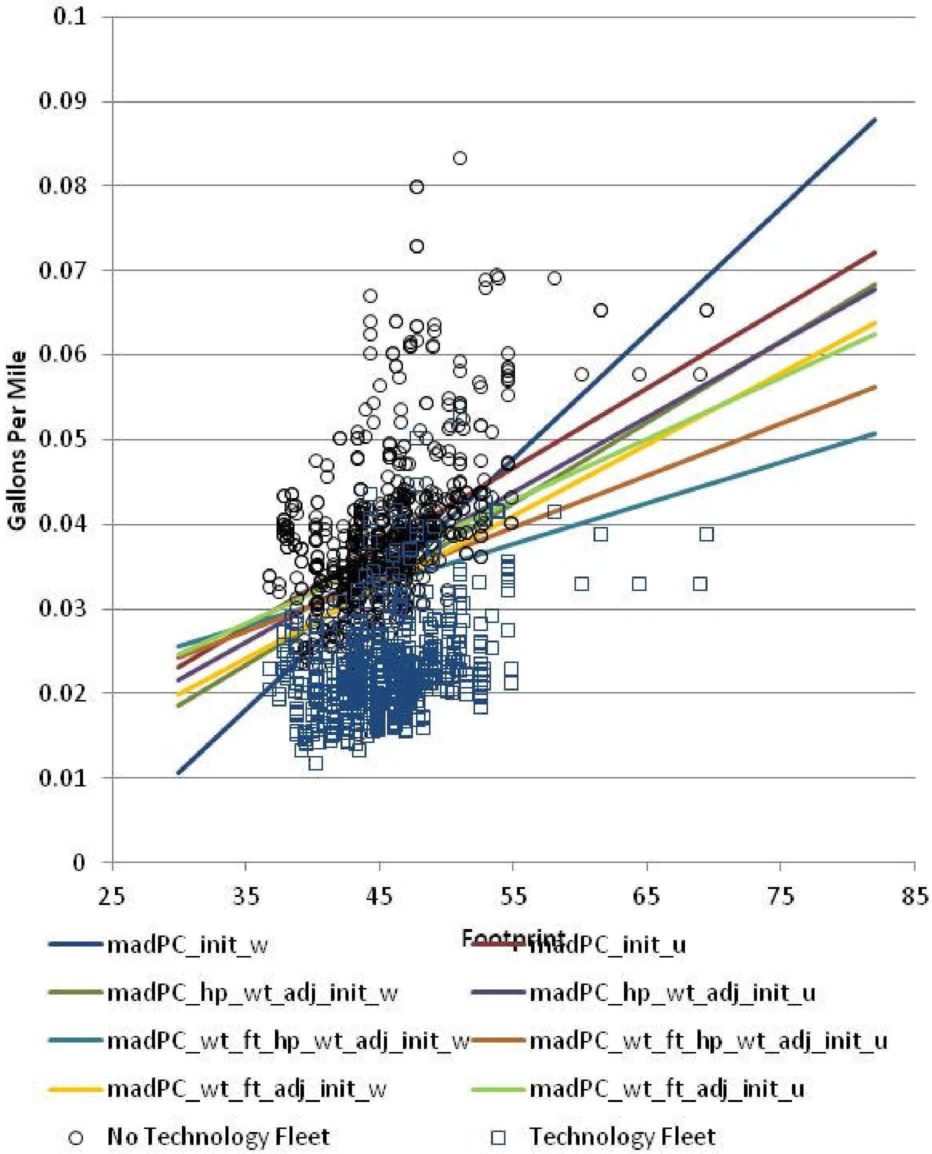

Figure 2-13 Best Fit Results for Various Regressions: Cars, No Added Technology, MAD

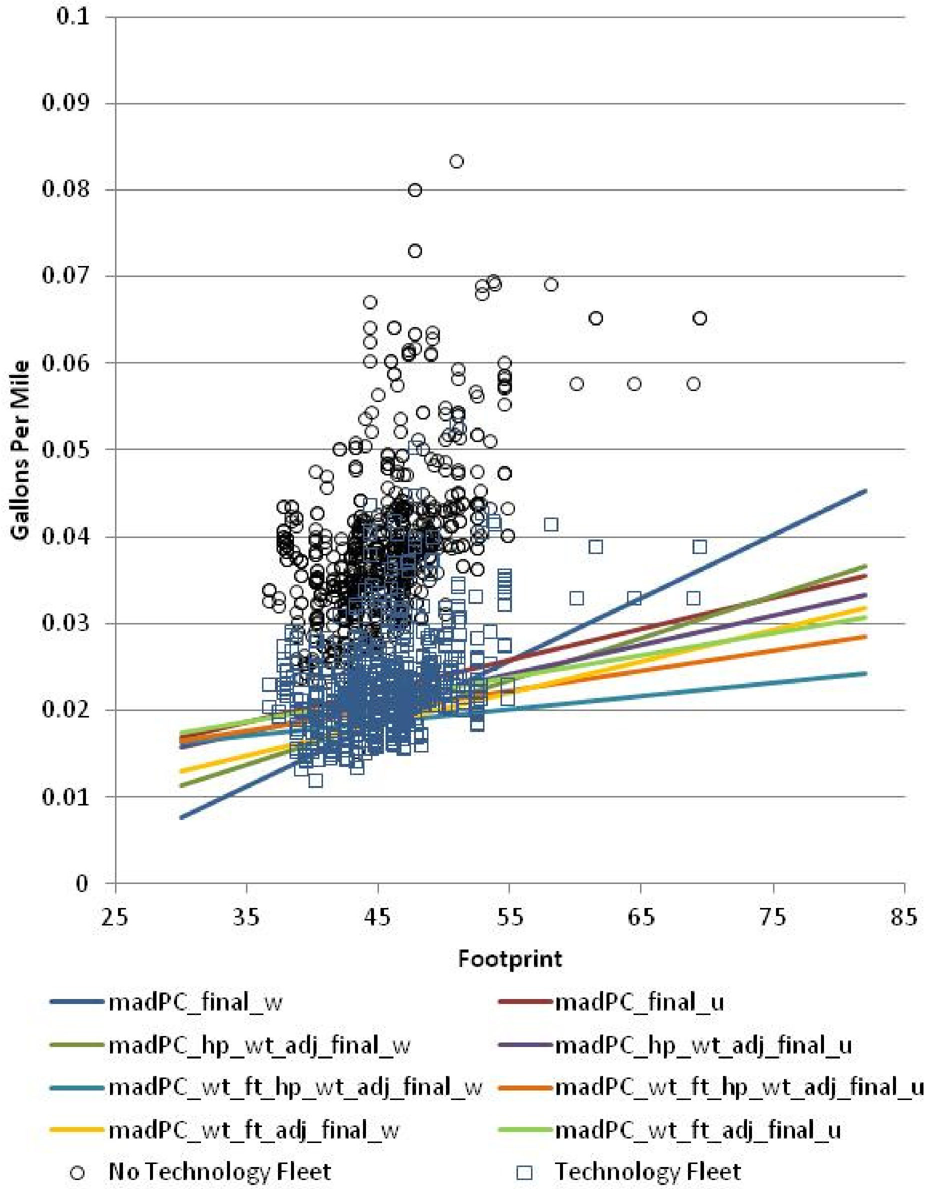

Figure 2-14 Best Fit Results for Various Regressions: Cars, Added Technology, MAD

The MAD regression results below in Figure 2-15 show a grouping of the fitted lines similar to that displayed in the OLS fits for trucks. As expected, an additional reduction in divergence is seen in the case where technology has been added, in Figure 2-15, which can be ascribed to the reduction in heterogeneity of the fleet brought about by the addition of the technology.

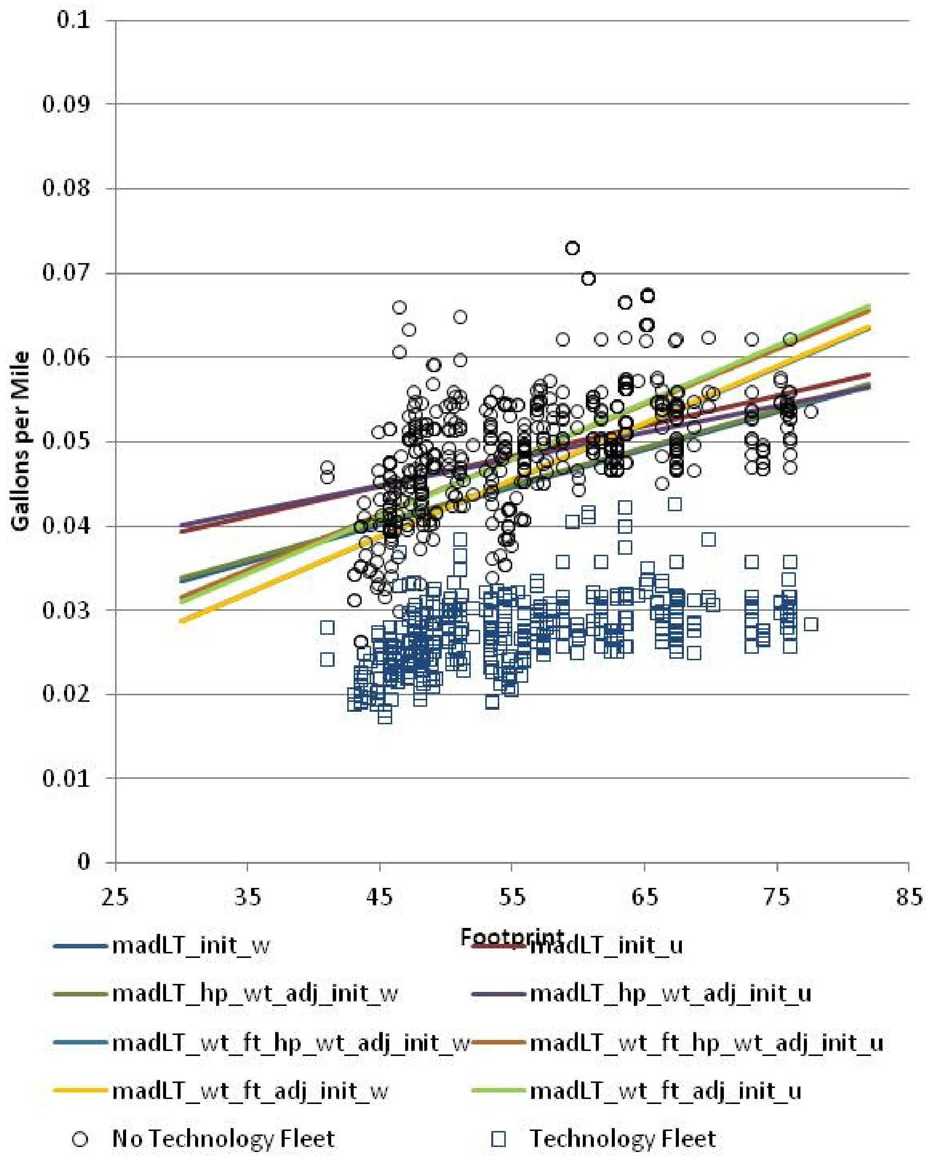

Figure 2-15 Best Fit Results for Various Regressions: Trucks, No Added Technology, MAD

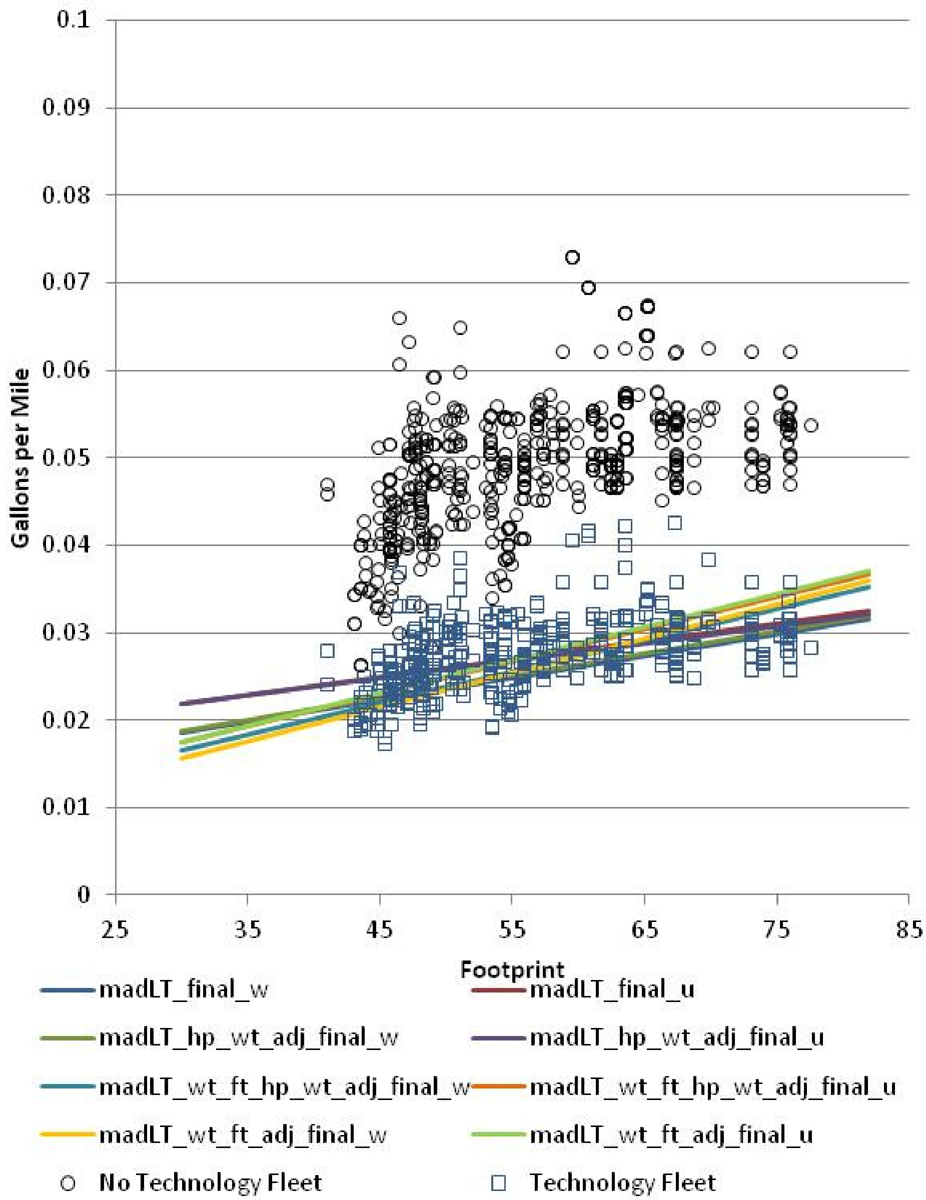

Figure 2-16 Best Fit Results for Various Regressions: Trucks, with Added Technology, MAD

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projections yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[fff]

2.4.2.10 Which methodology did the agencies choose for the proposal, and why was it reasonable?

For the proposal, the choice among the alternatives presented above was to use the OLS formulation, on sales-weighted data, using a fleet that has had technology applied, and after adjusting the data for the effect of weight-to-footprint, as described above. The agencies believe that this represented a technically reasonable approach for purposes of developing target curves to define the proposed standards, and that it represents a reasonable trade-off among various considerations balancing statistical, technical, and policy matters, which include the statistical representativeness of the curves considered and the steepness of the curve chosen. The agencies judged the application of technology prior to curve fitting to provide a reasonable means—one consistent with the rule's objective of encouraging manufacturers to add technology in order to increase fuel economy and reduce GHG emissions—of reducing variation in the data and thereby helping to estimate a relationship between fuel consumption/CO_2 and footprint.

Similarly, for the agencies' NPRM MY 2008-based market-forecast and the agencies' estimates of future technology effectiveness, the inclusion of the weight-to-footprint data adjustment prior to running the regression also helped to improve the fit of the curves by reducing the variation in the data, and the agencies believed that the benefits of this adjustment for the proposed rule likely outweighed the potential that resultant curves might somehow encourage reduced load carrying capability or vehicle performance (note that we were not suggesting that we believed these adjustments would reduce load carrying capability or vehicle performance). In addition to reducing the variability, the truck curve was also steepened, and the car curve flattened compared to curves fitted to sales weighted data that do not include these normalizations. The agencies agreed with manufacturers of full-size pick-up trucks that in order to maintain towing and hauling utility, the engines on pick-up trucks must be more powerful, than their low "density" nature statistically suggested based on the agencies' NPRM MY 2008-based market forecast and the agencies' estimates of the effectiveness of different fuel-saving technologies. Therefore, the agencies judged that it may be more appropriate (*i.e.*, in terms of relative compliance challenges faced by different light truck manufacturers) to adjust the slope of the curves defining fuel economy and CO_2 targets.

The results of the normalized regressions are displayed in Table, below.[ggg]

Table 2-7 Regression Results

[fff] Docket No. NHTSA-2010-0131.

[ggg] As presented in the draft TSD supporting the NPRM, this table erroneously reported coefficients from the regression using normalization based on differences in horsepower to weight rather than differences in weight per footprint. The differences in this Table as presented in this final TSD reflect this correction.

Vehicle	Slope (gallons/mile)	Constant (gallons/mile)
Passenger cars	0.00037782	0.00181033
Light trucks	0.00038891	0.00401336

Updating this analysis using the corrected MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[hhh]

As described above, however, other approaches are also technically reasonable, and also represent a way of expressing the underlying relationships. The agencies revisited the analysis for the final rule, after correcting the underlying MY 2008 based market forecast, developing a MY 2010 based market forecast, updating estimates of technology effectiveness and cost, and after considering relevant public comments. As presented below in section 2.6, results of these updated analyses were generally similar to those supporting the NPRM analysis results, and the agencies' balancing of considerations led the agencies to select final curves unchanged from the NPRM curves.

As shown in the figures below, the line represents the sales-weighted OLS regression fit of gallons per mile regressed on footprint, with the proposal data first adjusted by weight to footprint, as described above. This introduces weight as an additional consideration into the slope of the footprint curve, although in a manner that adjusts the data as described above, and thus maintains a simple graphical interpretation of the curve in a two dimensional space (gallons per mile and footprint).

[hhh] Docket No. NHTSA-2010-0131.

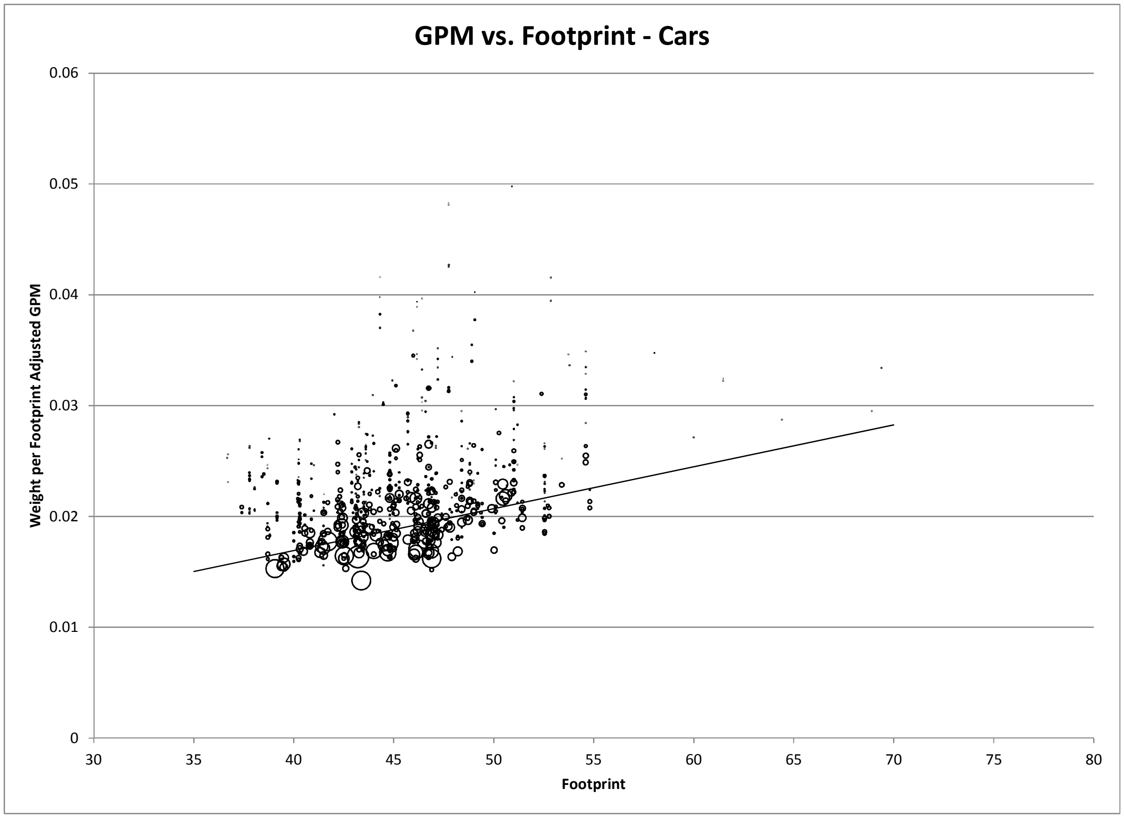

Figure 2-17 Gallons per Mile versus Footprint, Cars

(Data adjusted by weight to footprint).

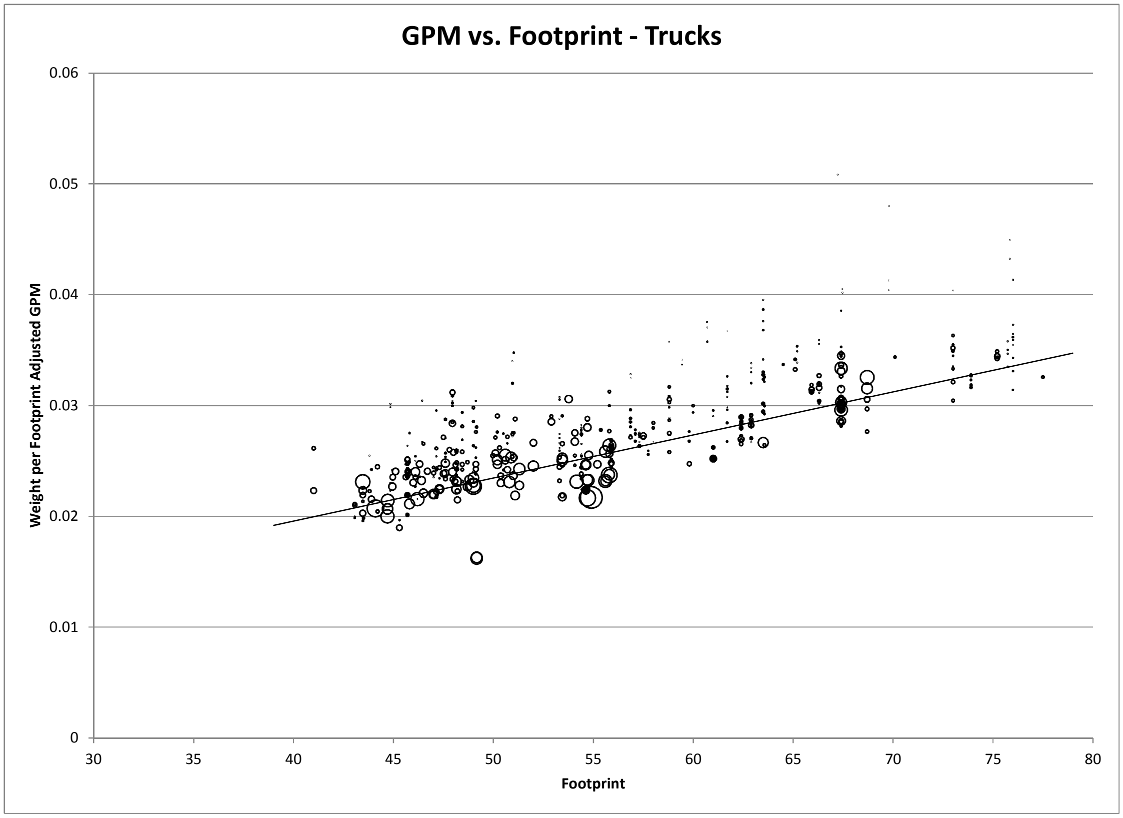

Figure 2-18 Gallons per Mile versus Footprint, Trucks

(data adjusted by weight to footprint).

Updating this analysis using the revised MY 2008- and the MY 2010-based fleet projection yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[iii]

In the preceding two figures, passenger car and light truck data is represented for the specification chosen, with the size of the observation scaled to sales. The agencies note with regard to light trucks that for the MYs 2012-2016 analysis NPRM and final rule analyses, some models of pickups are aggregated , when, for example, the same pickup had been available in different cab configurations with different wheelbases.[16] For the analysis presented above, these models have been disaggregated and are represented individually, which leads to a slightly different outcome in the regression results than had they remained aggregated.

[iii] Docket No. NHTSA-2010-0131.

2.4.2.11 Implications of the adopted slopes compared to the slopes in MYs 2012-2016 Rules

The slope first proposed, and now adopted by the agencies has several implications relative to the MY 2016 curves, with the majority of changes affecting the truck curve. The selected car curve has a slope similar to that finalized in the MYs 2012-2016 rulemaking (4.7 g/mile in MY 2016, vs. 4.5 g/mile proposed in MY 2017). By contrast, the truck curve is steeper in MY 2017 than in MY 2016 (4.0 g/mile in MY 2016 vs. 4.9 g/mile in MY 2017). As discussed previously, a steeper slope relaxes the stringency of targets for larger vehicles relative to those for smaller vehicles, thereby shifting relative compliance burdens among manufacturers based on their respective product mix. Comments regarding the slope of the agencies' proposed curves are discussed in Section II.C of the preamble to today's final rule.

2.5 Once the agencies determined the appropriate slope for the sloped part, how did the agencies determine the rest of the mathematical function?

The agencies continue to believe that without a limit at the smallest footprints, the function—whether logistic or linear—can reach values that would be unfairly burdensome for a manufacturer that elects to focus on the market for small vehicles; depending on the underlying data, an unconstrained form could result in stringency levels that are technologically infeasible and/or economically impracticable for those manufacturers that may elect to focus on the smallest vehicles. On the other side of the function, without a limit at the largest footprints, the function may provide no floor on required fuel economy. Also, the safety considerations that support the provision of a disincentive for downsizing as a compliance strategy apply weakly, if at all, to the very largest vehicles. Limiting the function's value for the largest vehicles thus leads to a function with an inherent absolute minimum level of performance, while remaining consistent with safety considerations.

Just as for slope, in determining the appropriate footprint and fuel economy values for the "cutpoints," the places along the curve where the sloped portion becomes flat, the agencies took a fresh look for purposes of this rulemaking, taking into account the updated market forecasts and new assumptions about the availability of technologies. The next two sections discuss the agencies' approach to cutpoints for the passenger car and light truck curves separately, as the policy considerations for each vary somewhat.

2.5.1 Cutpoints for Passenger Car curve

The passenger car fleet upon which the agencies based the proposed target curves for MYs 2017-2025 was derived from MY 2008 data, as discussed above. In MY 2008, passenger car footprints ranged from 36.7 square feet, the Lotus Exige 5, to 69.3 square feet, the Daimler Maybach 62. In that fleet, several manufacturers offer small, sporty coupes below 41 square feet, such as the BMW Z4 and Mini, Honda S2000, Mazda MX-5 Miata, Porsche Carrera and 911, and Volkswagen New Beetle. Because such vehicles represent a small portion (less than 10 percent) of the passenger car market, yet often have performance, utility, and/or structural characteristics that could make it technologically infeasible and/or economically impracticable for manufacturers focusing on such vehicles to achieve the very challenging average requirements that could apply in the absence of a constraint, EPA and NHTSA again proposed to cut off the sloped portion of the passenger car function at 41 square feet, consistent with the MYs 2012-2016 rulemaking. The agencies recognized that for manufacturers who make small vehicles in this size range, putting the cutpoint at 41 square feet creates some incentive to downsize (*i.e.*, further reduce the size, and/or increase the production of models currently smaller than 41 square feet) to make it easier to meet the target. Putting the cutpoint here may also create the incentive for manufacturers who do not currently offer such models to do so in the future. However, at the same time, the agencies believe that there is a limit to the market for cars smaller than 41 square feet -- most consumers likely have some minimum expectation about interior volume, among other things. The agencies thus believe that the number of consumers who will want vehicles smaller than 41 square feet (regardless of how they are priced) is small, and that the incentive to downsize to less than 41 square feet in response to this proposal, if present, will be at best minimal. On the other hand, the agencies note that some manufacturers are introducing mini cars not reflected in the agencies MY 2008-based market forecast, such as the Fiat 500, to the U.S. market, and that the footprint at which the curve is limited may affect the incentive for manufacturers to do so.

Above 56 square feet, the only passenger car models present in the MY 2008 fleet were four luxury vehicles with extremely low sales volumes—the Bentley Arnage and three versions of the Rolls Royce Phantom. As in the MYs 2012-2016 rulemaking, NHTSA and EPA therefore proposed again to cut off the sloped portion of the passenger car function at 56 square feet.[jjj]

While meeting with manufacturers prior to issuing the proposal, the agencies received comments from some manufacturers that, combined with slope and overall stringency, using 41 square feet as the footprint at which to cap the target for small cars would result in unduly challenging targets for small cars. The agencies do not agree. No specific vehicle need meet its target (because standards apply to fleet average performance), and maintaining a sloped function toward the smaller end of the passenger car market is important to discourage unsafe downsizing, the agencies thus proposed to again "cut off" the passenger car curve at 41 square feet, notwithstanding these comments.

. The agencies discuss the comments that were received for the cutpoints on both passenger car and light truck curves in the next section.

[jjj] The MY 2010 based market forecast has a similarly small number of cars above a footprint of 56 sq ft. These nine vehicle models include 5 Rolls Royce models, a Maybach 57-S and three BMW vehicles, with fewer than 20,000 total projected sales in any model year during this timeframe.

2.5.2 Cutpoints for Light Truck curve

The light truck fleet upon which the agencies based the proposed target curves for MYs 2017-2025, like the passenger car fleet, was derived from MY 2008 data, as discussed in Section 2.4 above. In MY 2008, light truck footprints ranged from 41.0 square feet, the Jeep Wrangler, to 77.5 square feet, the Toyota Tundra. For consistency with the curve for passenger cars, the agencies proposed to cut off the sloped portion of the light truck function at the same footprint, 41 square feet, although we recognized that no light trucks are currently offered below 41 square feet. With regard to the upper cutpoint, the agencies heard from a number of manufacturers during the discussions leading up to the proposal of the MYs 2017-2025 standards that the location of the cutpoint in the MYs 2012-2016 rules, 66 square feet, resulted in very challenging targets for the largest light trucks in the later years of that rulemaking (although, because CAFE and GHG standards are based on average performance, manufacturers to not need to ensure that every vehicle model meets its fuel economy and GHG targets). See 76 FR at 74864-65. Those manufacturers requested that the agencies extend the cutpoint to a larger footprint, to reduce targets for the largest light trucks which represent a significant percentage of those manufacturers' light truck sales. At the same time, in re-examining the light truck fleet data, the agencies concluded that aggregating pickup truck models in the MYs 2012-2016 rule had led the agencies to underestimate the impact of the different pickup truck model configurations above 66 square feet on manufacturers' fleet average fuel economy and CO2 levels (as discussed immediately below). In disaggregating the pickup truck model data, the impact of setting the cutpoint at 66 square feet after model year 2016 became clearer to the agencies.

In the agencies' view, these comments have a legitimate basis. The agencies' market forecast used at proposal includes about 24 vehicle configurations above 74 square feet with a total volume of about 50,000 vehicles or less during any MY in the 2017-2025 time frame.[kkk] While a relatively small portion of the overall truck fleet, for some manufacturers, these vehicles are a non-trivial portion of their sales. As noted above, the very largest light trucks have significant load-carrying and towing capabilities that make it particularly challenging for manufacturers to add fuel economy-improving/CO_2-reducing technologies in a way that maintains the full functionality of those capabilities.[lll] Considering manufacturer CBI and our estimates of the impact of the 66 square foot cutpoint for future model years, the agencies determined to adopt curves that transition to a different cut point. While noting that no specific vehicle need meet its target (because standards apply to fleet average performance), we believe that the information provided to us by manufacturers (*i.e.*, information provided regarding the accumulated impacts, especially on manufacturers' credit balances, of CAFE standards since MY2005 and GHG standards since MY2012) and our own analysis supported the gradual extension of the cutpoint for large light trucks in the proposal from 66 square feet

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[kkk] In the MY2010 based market forecast, there are 14 vehicle configurations with a total volume of 130,000 vehicles or less during any MY in the 2017-2025 time frame. This is a similarly small portion of the overall number of vehicle models or vehicle sales.

[lll] Comments on this issue are discussed in section 0.

in MY 2016 out to a larger footprint square feet before MY 2025. The agencies' analyses with regard to this topic, and how it relates to the stringency of the standards, are presented in preamble sections III.D and IV.F and summarized in preamble section II.C.

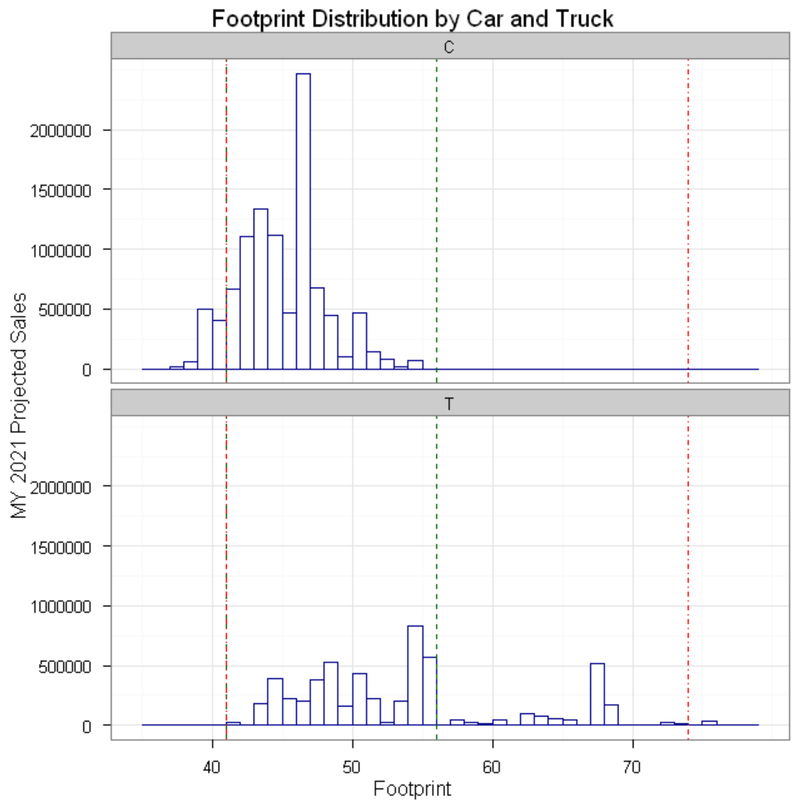

Figure 2-19 Footprint Distribution by Car and Truck*

*Proposed truck cutpoints for MY 2025 shown in red, car cutpoints shown in green

Updating this analysis using the revised MY 2008- and the MY 2010-based market forecasts yielded results generally similar to those shown above. Detailed results of the analyses with the final rulemaking fleet projections are presented in a memorandum available in NHTSA's docket.[mmm]

The agencies proposed to phase in the higher cutpoint for the truck curve in order to avoid any backsliding from the MY 2016 standard. A target that is feasible in one model year should never become less feasible in a subsequent model year since manufacturers should have no reason to remove fuel economy-improving/CO_2-reducing technology from a vehicle

[mmm] Docket No. NHTSA-2010-0131.

once it has been applied. Put another way, the agencies proposed to not allow "curve crossing" from one model year to the next. In proposing MYs 2011-2015 CAFE standards and promulgating MY 2011 standards, NHTSA proposed and requested comment on avoiding curve crossing, as an "anti-backsliding measure."[17] The MY 2016 2-cycle test curves are therefore a floor for the MYs 2017-2025 curves. For passenger cars, which have minimal change in slope from the MY 2012-2016 rulemakings and no change in cut points, there were no curve crossing issues in the proposed (or final) standards.

The minimum stringency determination was done using the two-cycle curves. Stringency adjustments for air conditioning and other credits were calculated after curves that did not cross were determined in two-cycle space. The year over year increase in these adjustments cause neither the GHG nor CAFE curves (with A/C) to contact the 2016 curves when charted.

The agencies received some comments on the selection of these cutpoints. ACEEE commented that the extension of the light truck cutpoint upward from 66 s.f. to 74 s.f. would reduce stringency for large trucks even though there is no safety-related reason to discourage downsizing of these trucks. Sierra Club and Volkswagen commented that moving this cutpoint could encourage trucks to get larger and may be detrimental to societal fatalities. Global Automakers commented that the cutpoint for the smallest light trucks should be set at approximately ten percent of sales (as for passenger cars) rather than at 41 square feet. Conversely, IIHS commented that, for both passenger cars and light trucks, the 41 s.f. cutpoint should be moved further to the left (*i.e.*, to even smaller footprints), to reduce the incentive for manufacturers to downsize the lightest vehicles.

The agencies have considered these comments regarding the cutpoint applied to the high footprint end of the target function for light trucks, and we judge there to be minimal risk that manufacturers would respond to this upward extension of the cutpoint by deliberately increasing the size of light trucks that are already at the upper end of marketable vehicle sizes, particularly as gasoline prices may continue to increase in the future. Such vehicles have distinct size, maneuverability, fuel consumption, storage, and other characteristics which differ from vehicles between 43 and 48 square feet, and are likely not be suited for all consumers in all usage scenarios. Further, larger vehicles typically also have additional production costs that make it unlikely that the sales of these vehicles will increase in response to changes in the cutpoint. Therefore, we remain concerned that not to extend this cutpoint to 74 s.f. would fail to take into adequate consideration the challenges to improving fuel economy and CO_2 emissions to the levels required by this final rule for vehicles with footprints larger than 66 s.f., given their increased utility, As noted above, while manufacturers are not required to ensure that every vehicle model meets its target, the agencies are concerned that standards with more stringent targets for large trucks would unduly burden full-line manufacturers active in the market for full-size pickups and other large light trucks, as discussed earlier, and evidenced by the agencies' estimates of differences between compliance burdens faced by OEMs active and not active in the market for full-size pickups. While some manufacturers have recently indicated[nnn] that buyers are currently willing to pay a premium for fuel economy improvements, the agencies are concerned that disparities in long-term regulatory requirements could lead to future market distortions undermining the economic practicability of the standards. Absent an upward extension of the cutpoint, such disparities would be even greater. For these reasons, the agencies do not expect that gradually extending the cutpoint to 74 s.f will incentivize the upsizing of large trucks and, thus, believe there will be no adverse effects on societal safety. Therefore, we are promulgating standards that, as proposed, gradually extend the truck curve cutpoint to 74 s.f. We have also considered the above comments by Global Automakers and IIHS on the cutpoints for the smallest passenger cars and light trucks. In our judgment, placing these cutpoints at 41 square feet continues to strike an appropriate balance between (a) not discouraging manufacturers from introducing new small vehicle models in the U.S. and (b) not encouraging manufacturers to downsize small vehicles.

2.5.3 Once the agencies determined the complete mathematical function shape, how did the agencies adjust the curves to develop the proposed standards and regulatory alternatives?

The curves discussed above all reflect the addition of technology to individual vehicle models to reduce technology differences between vehicle models before fitting curves. This application of technology was conducted not to directly determine the proposed standards, but rather for purposes of technology adjustments, and set aside considerations regarding potential rates of application (*i.e.*, phase-in caps), and considerations regarding economic implications of applying specific technologies to specific vehicle models. The following sections describe further adjustments to the curves discussed above, that affect both the shape of the curve (section 2.5.3.1), and the location of the curve (2.5.3.2), that helped the agencies determine curves that defined the proposed standards.

2.5.3.1 Adjusting for Year over Year Stringency

As in the MYs 2012-2016 rules, the agencies developed curves defining regulatory alternatives for consideration by "shifting" these curves. For the MYs 2012-2016 rules, the agencies did so on an absolute basis, offsetting the fitted curve by the same value (in gpm or g/mi) at all footprints. In developing the proposal for MYs 2017-2025, the agencies reconsidered the use of this approach, and concluded that after MY 2016, curves should be offset on a relative basis—that is, by adjusting the entire gpm-based curve (and, equivalently, the CO_2 curve) by the same percentage rather than the same absolute value. The agencies' estimates of the effectiveness of these technologies are all expressed in relative terms—that is, each technology (with the exception of A/C) is estimated to reduce fuel consumption (the inverse of fuel economy) and CO_2 emissions by a specific percentage of fuel consumption without the technology. It is, therefore, more consistent with the agencies' estimates of

[nnn] For example, in its June 11, 2012 edition, *Automotive News* quoted a Ford sales official saying that "fuel efficiency continues to be a top purchaser driver." ("More MPG – ASAP", *Automotive News*, Jun 11, 2012.)

technology effectiveness to develop standards and regulatory alternatives by applying a proportional offset to curves expressing fuel consumption or emissions as a function of footprint. In addition, extended indefinitely (and without other compensating adjustments), an absolute offset would eventually (*i.e.*, at very high average stringencies) produce negative (gpm or g/mi) targets. Relative offsets avoid this potential outcome. Relative offsets do cause curves to become, on a fuel consumption and CO_2 basis, flatter at greater average stringencies; however, as discussed above, this outcome remains consistent with the agencies' estimates of technology effectiveness. In other words, given a relative decrease in average required fuel consumption or CO_2 emissions, a curve that is flatter by the same relative amount should be equally challenging in terms of the potential to achieve compliance through the addition of fuel-saving technology.

On this basis, and considering that the "flattening" occurs gradually for the regulatory alternatives the agencies have evaluated, the agencies conclude that this approach to offsetting the curves to develop year-by-year regulatory alternatives neither re-creates a situation in which manufacturers are likely to respond to standards in ways that compromise highway safety, nor undoes the attribute-based standard's more equitable balancing of compliance burdens among disparate manufacturers. The agencies sought comment on these conclusions, and on any other means that might avoid the potential negative outcomes discussed above. As indicated earlier, ACEEE and the Alliance both expressed support for the application of relative adjustments in order to develop year-over-year increases in the stringency of fuel consumption and CO_2 targets, although the Alliance also commented that this approach should be revisited as part of the mid-term evaluation.

2.5.3.2 Adjusting for anticipated improvements to mobile air conditioning systems

The fuel economy values in the agencies' market forecasts are based on the 2-cycle (*i.e.*, city and highway) fuel economy test and calculation procedures that do not reflect potential improvements in air conditioning system efficiency, refrigerant leakage, or refrigerant Global Warming Potential (GWP). Recognizing that there are significant and cost effective potential air conditioning system improvements available in the rulemaking timeframe (discussed in detail below in Chapter 5), the agencies are increasing the stringency of the target curves based on the agencies' assessment of the capability of manufacturers to implement these changes. For the proposed CAFE standards and alternatives, an offset was included based on air conditioning system efficiency improvements, as these improvements are the only improvements that effect vehicle fuel economy. For the proposed GHG standards and alternatives, a stringency increase was included based on air conditioning system efficiency, leakage and refrigerant improvements. As discussed in Chapter 5 of the joint TSD, the air conditioning system improvements affect a vehicle's fuel efficiency or CO_2 emissions performance as an additive stringency increase, as compared to other fuel efficiency improving technologies which are multiplicative. Therefore, in adjusting target curves for improvements in the air conditioning system performance, the agencies adjusted the target curves by additive stringency increases (or vertical shifts) in the curves.

For the GHG target curves, the offset for air conditioning system performance is being handled in the same manner as for the MYs 2012-2016 rules. For the CAFE target curves, NHTSA for the first time is accounting for potential improvements in air conditioning system performance. Using this methodology, the agencies first use a multiplicative stringency adjustment for the sloped portion of the curves to reflect the effectiveness on technologies other that air conditioning system technologies, creating a series of curve shapes that are “fanned” based on two-cycle performance. Then the curves are offset vertically by the air conditioning improvement by an equal amount at every point.

2.6 What does the agencies’ updated analysis indicate?

As discussed above in Chapter 1, the agencies have used two different market forecasts to conduct analyses supporting today’s final rule. The first, referred to here as the “MY 2008-Based Fleet Projection,” is largely identical to that used for analysis supporting the NPRM, but includes some corrections (in particular, to the footprint of some vehicle models) discussed in Chapter 1 of this TSD. The second, referred to here as the “MY 2010-Based Fleet Projection,” is a post-proposal market forecast based on the MY 2010 fleet of vehicles; the development of this 2010 based fleet projection is discussed in Chapter 1.

Having made these changes, the agencies repeated the normalization and statistical analyses describe above, following the same approaches as used in the analysis supporting the NPRM. The tables and charts that follow compare the results of NHTSA’s updated analysis to those of NHTSA’s prior analysis, and compare the resultant fitted lines to the lines (one each for passenger cars and light trucks) selected for purposes of developing the proposed attribute-based standards. The charts below present details of the results in graphical form.

Table 2-8 Fitted Coefficients (Slope in gpm/sf, Intercept in gpm), Passenger Cars

Normalized for Technology Differences	Normalized for Differences in Power/Weight	Normalized for Differences in Weight/Footprint	Sales-Weighted	Regression Technique	Slope - NPRM Analysis	Slope - MY2008-Based Market Forecast	Slope - MY2010-Based Market Forecast	Intercept - NPRM Analysis	Intercept - MY2008-Based Market Forecast	Intercept - MY2010-Based Market Forecast
Yes	No	No	Yes	OLS	0.000648	0.000510	0.000472	-0.01027	-0.00450	-0.00376
Yes	No	No	No	OLS	0.000513	0.000464	0.000502	0.00009	0.00184	-0.00076
Yes	No	No	Yes	MAD	0.000725	0.000560	0.000427	-0.01408	-0.00699	-0.00210
Yes	No	No	No	MAD	0.000359	0.000334	0.000445	0.00610	0.00650	0.00076
Yes	Yes	No	Yes	OLS	0.000431	0.000293	0.000248	-0.00052	0.00520	0.00643
Yes	Yes	No	No	OLS	0.000399	0.000351	0.000398	0.00336	0.00508	0.00221
Yes	Yes	Yes	Yes	OLS	0.000161	0.000131	0.000093	0.01155	0.01238	0.01349
Yes	Yes	Yes	No	OLS	0.000264	0.000250	0.000268	0.00844	0.00873	0.00736
No	No	No	Yes	MAD	0.001486	0.001220	0.001058	-0.03401	-0.02131	-0.01670
No	No	No	No	MAD	0.000942	0.000959	0.000995	-0.00507	-0.00572	-0.00944
No	No	No	Yes	OLS	0.001345	0.001175	0.001096	-0.02766	-0.01974	-0.01806
No	No	No	No	OLS	0.001109	0.001085	0.001099	-0.01122	-0.00983	-0.01259
No	Yes	No	Yes	OLS	0.000984	0.000800	0.000737	-0.01144	-0.00299	-0.00176
No	Yes	No	No	OLS	0.000920	0.000890	0.000933	-0.00579	-0.00425	-0.00785
No	Yes	Yes	Yes	OLS	0.000481	0.000452	0.000403	0.01103	0.01242	0.01336
No	Yes	Yes	No	OLS	0.000669	0.000673	0.000654	0.00367	0.00358	0.00319
Yes	No	Yes	Yes	OLS	<u>0.000378</u>	0.000348	0.000316	<u>0.00181</u>	0.00268	0.00330
Yes	No	Yes	No	OLS	0.000378	0.000362	0.000371	0.00517	0.00550	0.00440

Note 1: Coefficients selected for NPRM shown underlined.

Note 2: "MY2008-Based Fleet Projection" refers to market forecast developed using (a) MY2008 vehicle models and characteristics, (b) AEO2011-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2009 by CSM (now owned by Global Insight).

Note 3: "MY2010-Based Fleet Projection" refers to market forecast developed using (a) MY2010 vehicle models and characteristics, (b) AEO2012-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2011 by J.D. Power (automotive forecasting service now owned by LMC).

Table 2-9 Fitted Coefficients (Slope in gpm/sf, Intercept in gpm), Light Trucks

Normalized for Technology Differences	Normalized for Differences in Power/Weight	Normalized for Differences in Weight/Footprint	Sales-Weighted	Regression Technique	Slope - NPRM Analysis	Slope - MY2008-Based Market Forecast	Slope - MY2010-Based Market Forecast	Intercept - NPRM Analysis	Intercept - MY2008-Based Market Forecast	Intercept - MY2010-Based Market Forecast
Yes	No	No	Yes	OLS	0.000269	0.000251	0.000256	0.01036	0.01012	0.00976
Yes	No	No	No	OLS	0.000233	0.000229	0.000198	0.01457	0.01376	0.01477
Yes	No	No	Yes	MAD	0.000250	0.000245	0.000278	0.01104	0.01060	0.00832
Yes	No	No	No	MAD	0.000204	0.000210	0.000231	0.01567	0.01438	0.01248
Yes	Yes	No	Yes	OLS	0.000253	0.000239	0.000237	0.01122	0.01078	0.01078
Yes	Yes	No	No	OLS	0.000221	0.000220	0.000201	0.01509	0.01414	0.01448
Yes	Yes	Yes	Yes	OLS	0.000373	0.000347	0.000340	0.00487	0.00507	0.00526
Yes	Yes	Yes	No	OLS	0.000395	0.000374	0.000303	0.00541	0.00558	0.00864
No	No	No	Yes	MAD	0.000448	0.000452	0.000481	0.01995	0.01984	0.01654
No	No	No	No	MAD	0.000356	0.000349	0.000440	0.02872	0.02914	0.02139
No	No	No	Yes	OLS	0.000491	0.000483	0.000470	0.01784	0.01825	0.01756
No	No	No	No	OLS	0.000433	0.000432	0.000423	0.02480	0.02486	0.02283
No	Yes	No	Yes	OLS	0.000462	0.000453	0.000446	0.01941	0.01988	0.01890
No	Yes	No	No	OLS	0.000410	0.000409	0.000426	0.02575	0.02579	0.02245
No	Yes	Yes	Yes	OLS	0.000669	0.000662	0.000629	0.00849	0.00881	0.00903
No	Yes	Yes	No	OLS	0.000710	0.000708	0.000609	0.00909	0.00919	0.01199
Yes	No	Yes	Yes	OLS	<u>0.000389</u>	0.000359	0.000358	<u>0.00401</u>	0.00441	0.00425
Yes	No	Yes	No	OLS	0.000407	0.000383	0.000301	0.00489	0.00520	0.00892

Note 1: Coefficients selected for NPRM shown underlined.

Note 2: "MY2008-Based Market Forecast" refers to market forecast developed using (a) MY2008 vehicle models and characteristics, (b) AEO2011-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2009 by CSM (now owned by Global Insight).

Note 3: "MY2010-Based Fleet Projection" refers to market forecast developed using (a) MY2010 vehicle models and characteristics, (b) AEO2012-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2011 by J.D. Power (automotive forecasting service now owned by LMC).

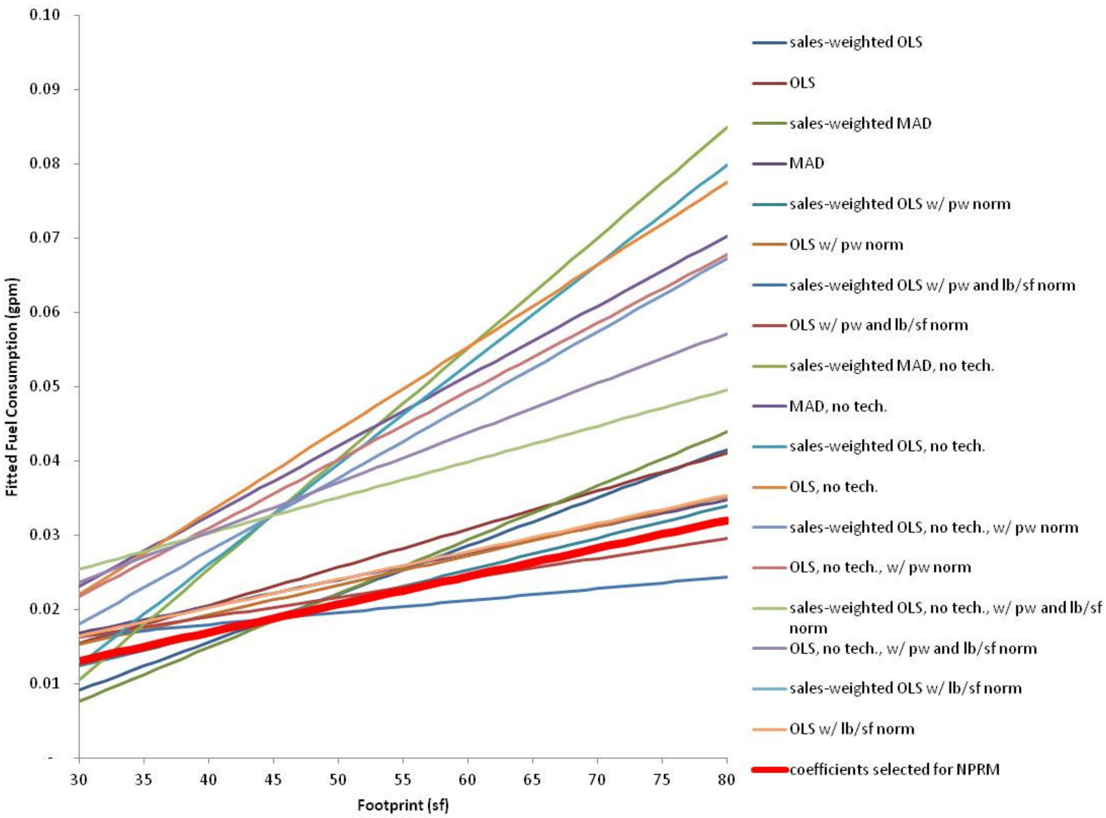

Figure 2-20 Fitted Lines, Passenger Cars, NPRM Analysis

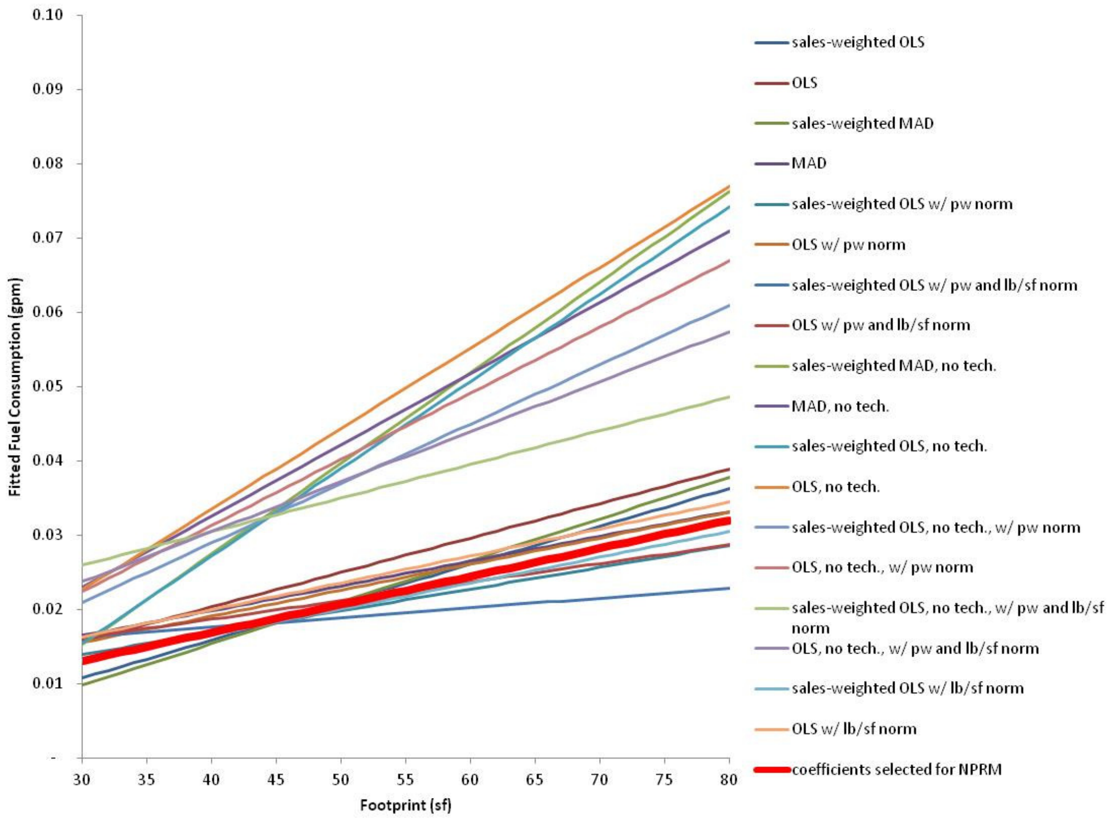

Figure 2-21 Fitted Lines, Passenger Cars, Corrected MY2008-Based Market Forecast

Note 1: Line based on coefficients selected for NPRM shown for comparison.

Note 2: “MY2008-Based Fleet Projection” refers to market forecast developed using (a) MY2008 vehicle models and characteristics, (b) AEO2011-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2009 by CSM (now owned by Global Insight).

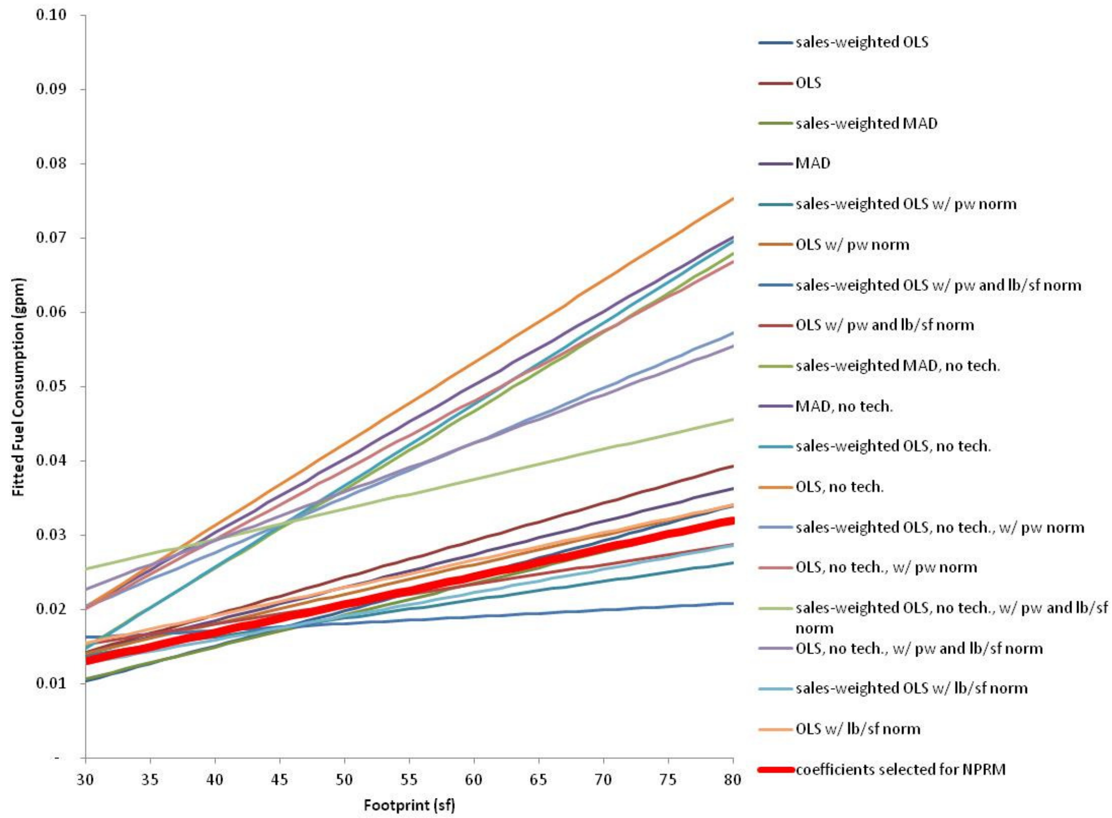

Figure 2-22 Fitted Lines, Passenger Cars, MY2010-Based Market Forecast

Note 1: Line based on coefficients selected for NPRM shown for comparison.

Note 2: “MY2010-Based Fleet Projection” refers to market forecast developed using (a) MY2010 vehicle models and characteristics, (b) AEO2012-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2011 by J.D. Power (automotive forecasting service now owned by LMC).

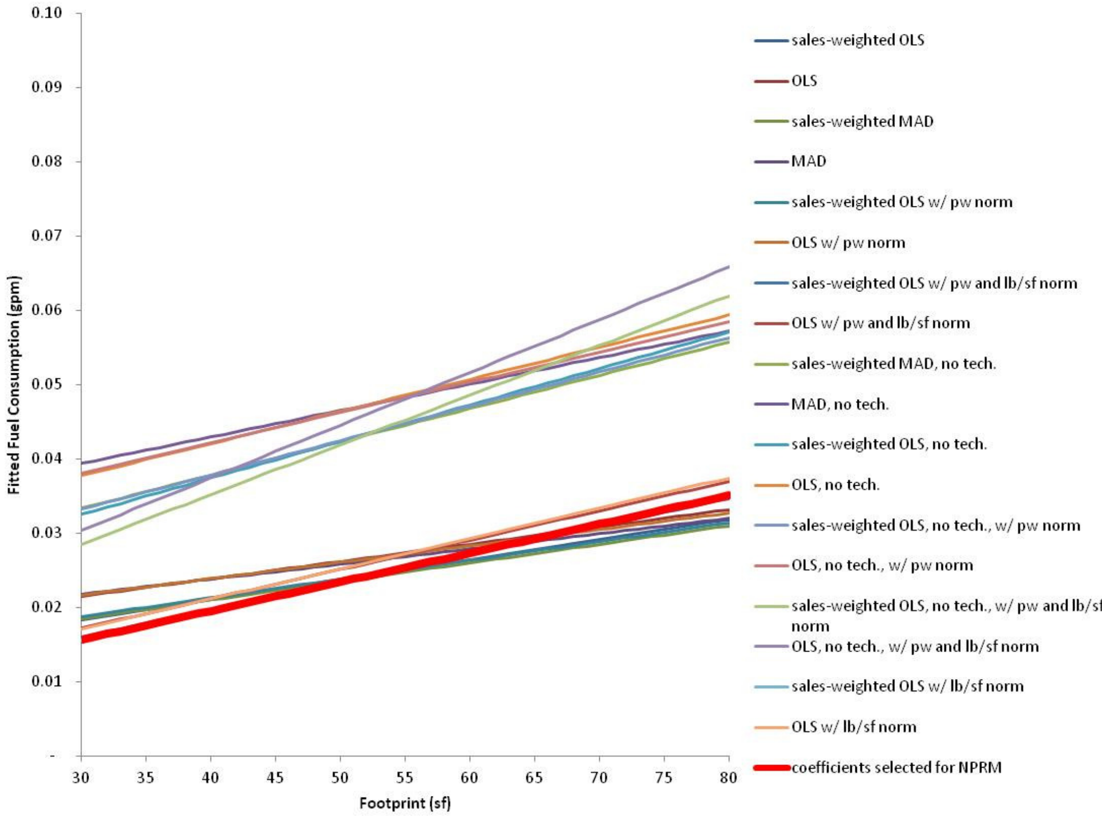

Figure 2-23 Fitted Lines, Light Trucks, NPRM Analysis

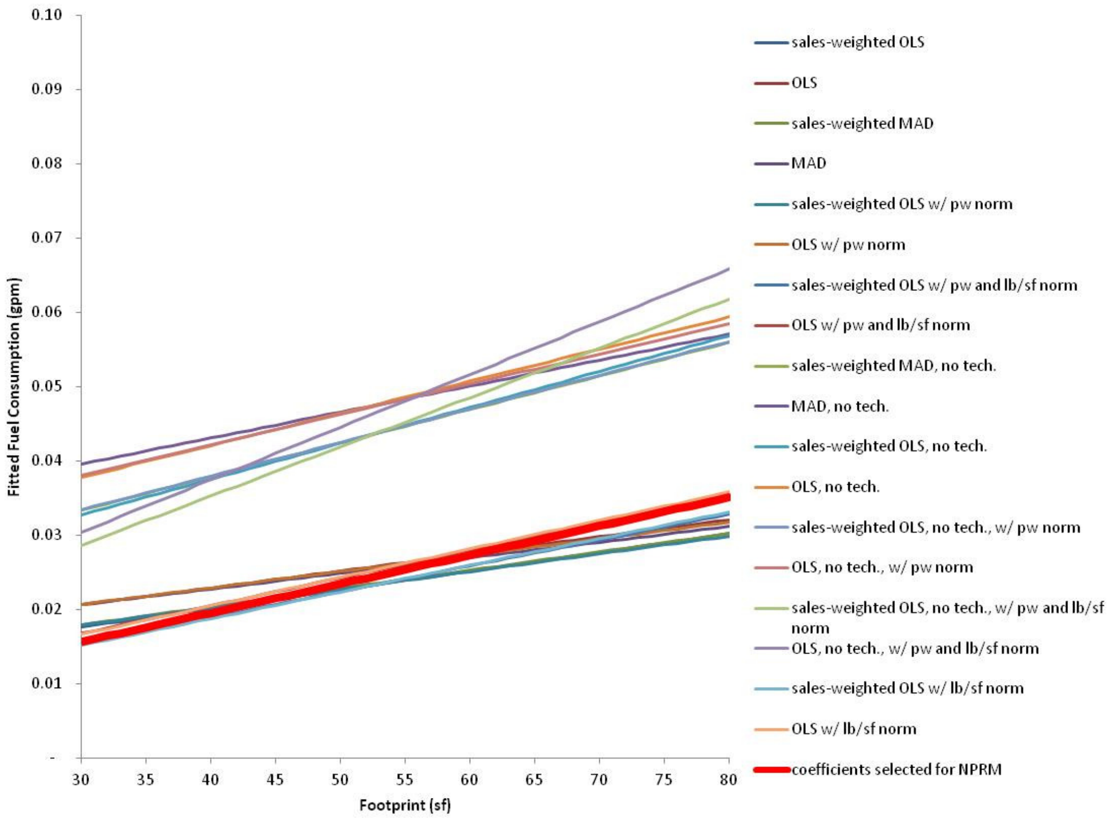

Figure 2-24 Fitted Lines, Light Trucks, Corrected MY2008-Based Market Forecast

Note 1: Line based on coefficients selected for NPRM shown for comparison.

Note 2: "MY2008-Based Fleet Projection" refers to market forecast developed using (a) MY2008 vehicle models and characteristics, (b) AEO2011-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2009 by CSM (now owned by Global Insight).

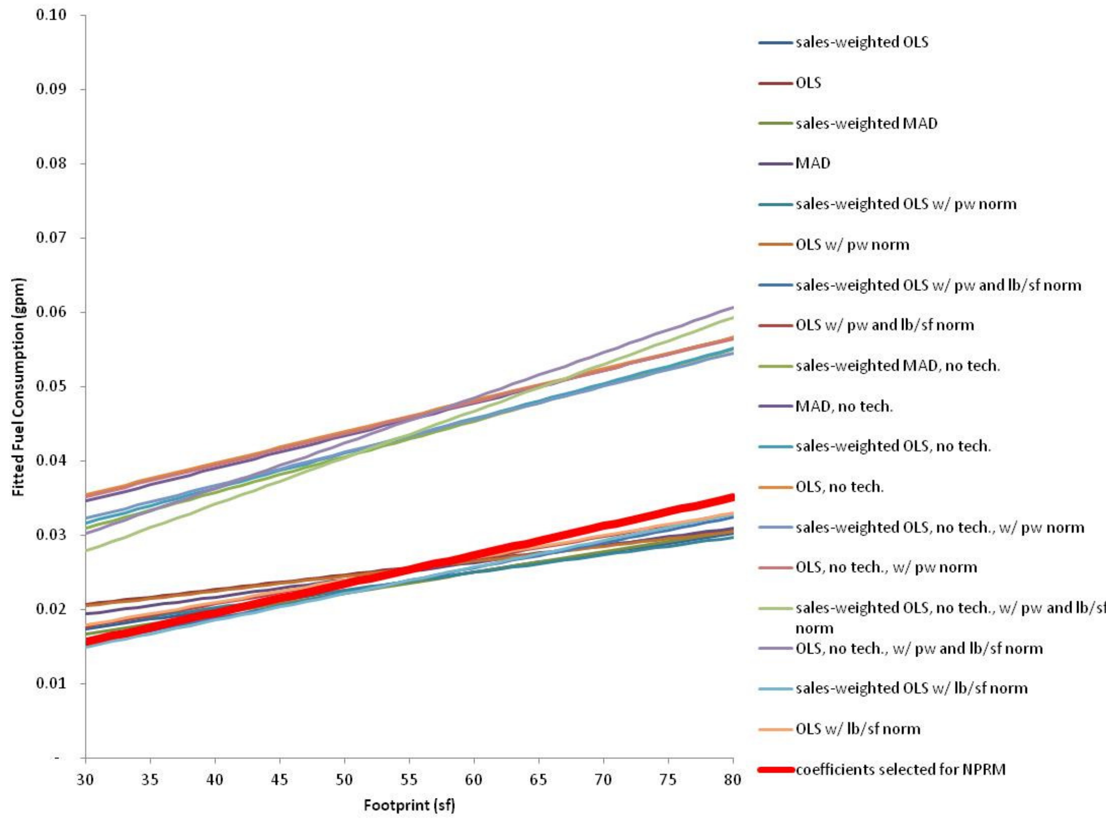

Figure 2-25 Fitted Lines, Light Trucks, MY2010-Based Market Forecast

Note 1: Line based on coefficients selected for NPRM shown for comparison.

Note 2: "MY2010-Based Fleet Projection" refers to market forecast developed using (a) MY2010 vehicle models and characteristics, (b) AEO2012-based overall passenger car and light truck volumes, and (c) manufacturer- and segment-level shares from forecast provided late 2011 by J.D. Power (automotive forecasting service now owned by LMC).

As discussed above, the selection of a calibrated functional form—in this case, a specific line expressing a relationship between fuel consumption and footprint—upon which to base attribute-based fuel economy and related GHG standards involves considering not just the apparent range of the relevant technical relationship, but also the potential implications for affected policy issues. The approaches described above provide a range of reasonable means of estimating relationships between observed or adjusted fuel consumption and footprint.

Having made corrections to the MY 2008-based fleet projection, and having developed a new MY 2010-based fleet projection, the agencies have obtained results generally similar, albeit not identical, to those obtained for the NPRM analysis. For any given method of estimating these lines, it is unlikely that the agencies could have obtained identical results after changing inputs. Also, there is no reason to expect that the MY 2008- and MY 2010-based fleet projections should produce identical results. Still, these differences were mostly small. Using both the corrected MY 2008-based passenger car market forecast and the new MY 2010-based forecast, three techniques produced fitted passenger car lines very close—in terms of average squared differences within the range of footprints between the selected cutpoints discussed above—to those selected for the NPRM: sales-weighted OLS without normalizations for differences in power/weight or weight/footprint, sales-weighted OLS with normalization for differences weight/footprint, and unweighted OLS with normalizations for differences in both power/weight and weight/footprint. For light trucks, two techniques did so for both the corrected MY 2008-based passenger car market forecast and the post-proposal MY 2010-based forecast: unweighted OLS with normalizations for differences in both power/weight and weight/footprint, and unweighted OLS with normalization for differences weight/footprint. Without any normalizations applied to the set of footprint and fuel economy values, unweighted OLS produced fitted slopes within 2% of the values obtained through the corresponding unweighted OLS analysis conducted in support of the NPRM. Also, as the above charts show, the resultant ranges (*i.e.*, areas in fuel consumption – footprint space) spanned by these methods are similar across the NPRM analysis and the updated analyses using the MY 2008- and MY 2010-based fleet projections.

Considering that the agencies have adopted an approach whereby regulatory alternatives are developed by shifting fitted curves on a multiplicative basis, results of several of the techniques evaluated here thus would produce regulatory alternatives virtually identical to those developed for the NPRM. For the method that produced results selected for development of the NPRM, relative adjustment of lines fitted to the corrected MY 2008-based market forecast and the MY 2010-based market forecast produces lines that are, between the footprint cutpoints discussed above (41-56 ft^2 and 41-74 ft^2 for passenger cars and light trucks, respectively), very close to the lines fitted for the NPRM (FIGURE Label):

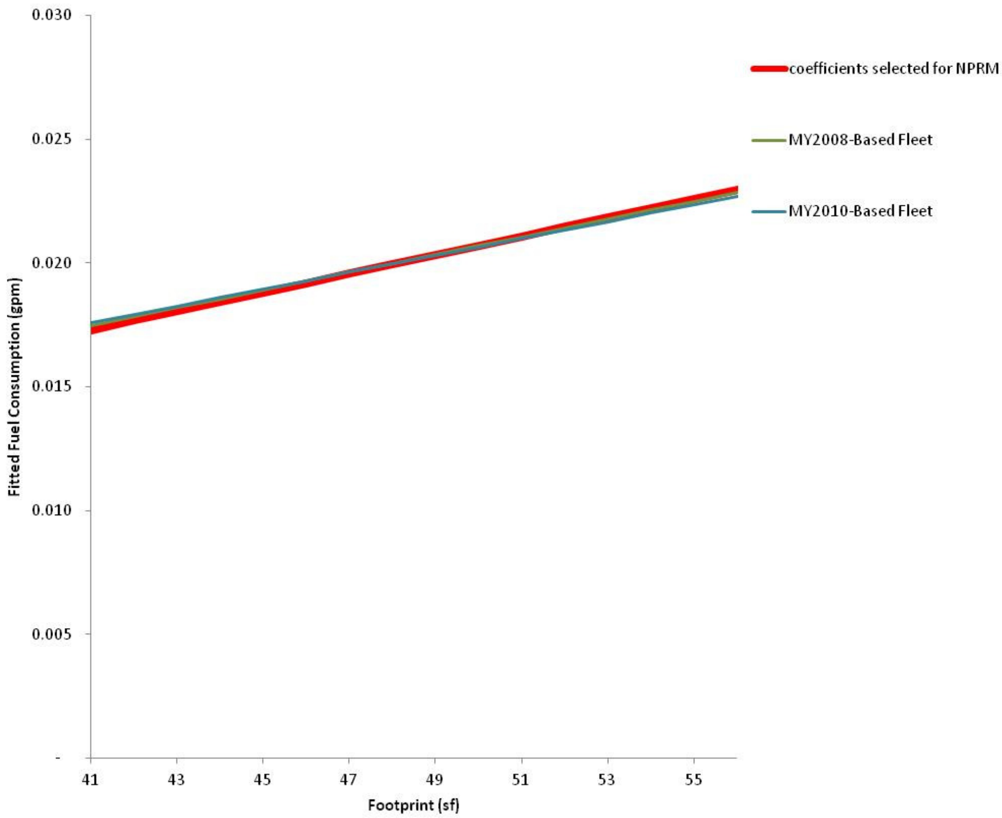

Figure 2-26 Sales-Weighted OLS with Normalization for Differences in Weight/Footprint, Passenger Cars, MY2008- and MY2010-Based Fleets Multiplicatively Adjusted

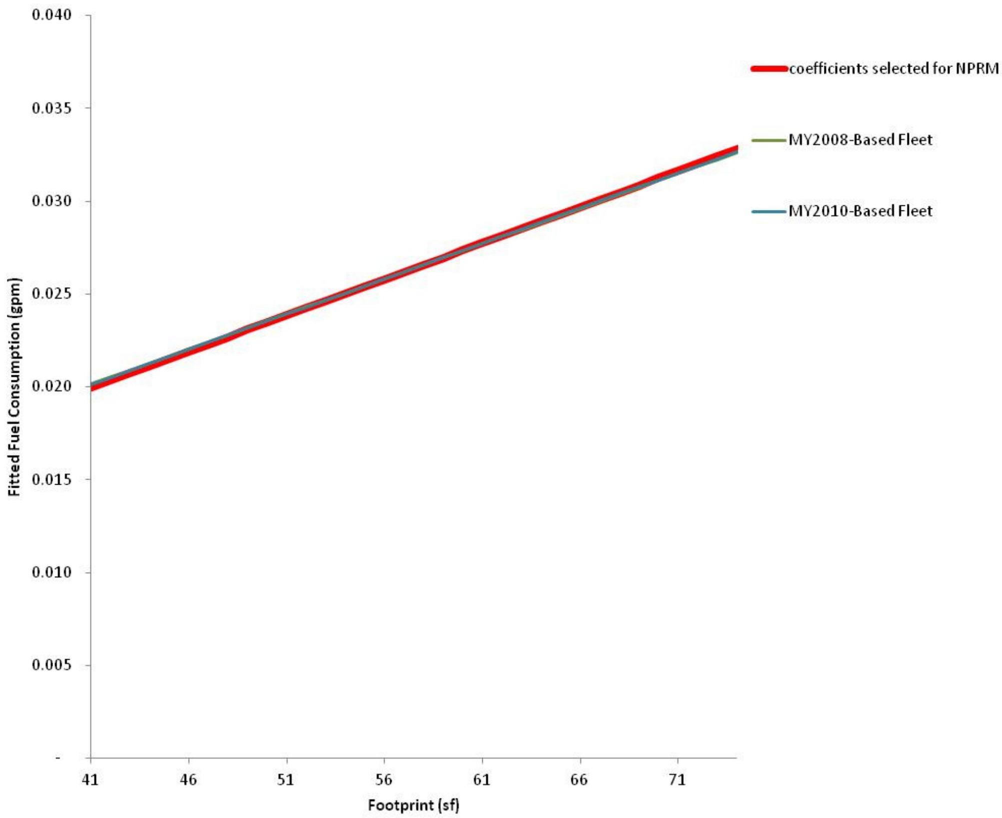

Figure 2-27 Sales-Weighted OLS with Normalization for Differences in Weight/Footprint, Light Trucks, MY2008- and MY2010-Based Fleets Multiplicatively Adjusted

The above figures show, for both for passenger cars and light trucks, that applying the techniques selected for the NPRM to either the corrected MY 2008-based fleet projection or the MY 2010-based fleet projection would produce regulatory alternatives with highly similar, but slightly flatter slopes than those in the NPRM. At any given average stringency, these slightly flatter slopes would produce slightly greater incentives for manufacturers to respond to new standards by reducing vehicle size. In addition, the slightly flatter slopes would slightly increase the stringency of targets for the largest vehicles relative to stringency of targets for the smallest vehicles. As discussed in preamble sections III.D and II.C.4.a, considering the accumulated effects of light truck CAFE standards having increased steadily since MY2004, and GHG standards from MY 2012, the agencies are concerned that flatter slopes could induce manufacturers of large light trucks toward overly aggressive penetration rates of advanced technologies into the sector, raising significant issues of cost, lead time and consumer acceptance which the agencies regard as inappropriate. As discussed above, the agencies remain concerned that about manufacturer incentives to reduce the capability to carry and/or tow heavy loads using full-size light trucks.

The agencies have thus looked at a range of analytical techniques for establishing a fitted line including using two market forecasts and using different approaches for the normalization for differences in technology content, normalization for differences in other vehicle attributes (*e.g.*, power/weight or weight/footprint or, plausibly, seating capacity, interior volume, towing capacity, etc.), and statistical techniques (*e.g.*, unweighted, sales-weighted, MAD, OLS). Considering (a) that the reasonable analytical techniques examined by the agencies produce a range of fitted lines, (b) that the future composition of the light vehicle market is subject to some uncertainty, and (c) that other aspects of the agencies' analysis are informed by policy implications, in the agencies' judgment, there is no single analytical method that is the sole "correct" way to establish the two fitted lines (one for passenger cars, one for light trucks) the agencies use to specify final standards. The agencies' updated analysis shows newly-fitted lines producing regulatory alternatives very close to the corresponding regulatory alternatives considered in the NPRM. This confirms that the standards are within the range of technically supportable possibilities.

While the agencies' analysis indicates that slopes spanning relatively wide ranges could be technically supportable, the agencies note that the final car standard is very similar to the slope of the MY 2016 standard, despite being based on a different analytical approach than the previous rule. As explained above, the agencies have selected a truck curve differing from that adopted for the previous rule (both slope and upper cut-point); the agencies expect that doing so will account for the future characteristics of the larger (work) trucks, and the manufacturers serving the future market for such trucks. The upper size cut-points for cars, and the lower size cut-point for both cars and trucks, are the same as in the previous rule. Without these adjustments, the agencies' believe that there would either be incentives for manufacturers to reduce the utility of these trucks, or that the manufacturer's compliance costs for reaching the targets would be disproportionately high (Preamble Sections III.C.5 and III.D).

Thus, in the agencies' judgment, the curves strike a reasonable and appropriate balance between the affected policy considerations—better reflecting the reasonable penetration rates of the technologies needed to achieve the standards and the lead time needed for implementation of those technologies, minimizing the incentive for manufacturers to respond to standards in ways that may either result in decreased utility or compromise safety (by downsizing vehicles with footprints on the sloped portion of mathematical functions defining fuel economy and GHG targets), and encouraging widespread penetration of technologies throughout both the car and light truck fleets at reasonable cost while achieving very significant energy and environmental benefits. Having repeated the analysis documented in the NPRM, and having done so based on two fleets (the corrected MY 2008-based market forecast, and the MY 2010-based market forecast), the agencies have demonstrated that, as proposed, the passenger car and light truck curves are well within technically supportable ranges. Slightly flatter standards would directionally have a potentially compromising effect on the safety-related incentives reflected by the promulgated curves, and potentially force more aggressive penetration of advanced technologies into work trucks in a way that raises issues of both increased cost and consumer acceptance. Conversely, slightly steeper standards would tend to increase the potential that manufacturers would respond to the standards by increasing vehicle size beyond levels the market would otherwise demand, in lieu of applying some fuel-saving technologies. For these reasons, the agencies are today promulgating standards using lines matching those used to develop proposed standards for the NPRM.

Additional discussion of the feasibility of the final standards is available in Preamble section III.D and IV.F.

Chapter 2: What are the Attribute-Based Curves the Agencies are Adopting

References:

[1] 49 U.S.C. 32902(a)(3)(A).

[2] 69 FR 38958 (June 29, 2004).

[3] 76 FR 57106, 57162-64, (Sept. 15, 2011).

[4] *See* 74 FR at 14359 (Mar. 30, 2009).

[5] 75 FR at 25362.

[6] *See generally* 74 FR at 49491-96; 75 FR at 25357-62.

[7] 68 FR 74920-74926.

[8] 74 FR 14359.

[9] See 75 FR at 25458

[10] 75 FR at 25363

[11] *See* 75 FR at 25359.

[12] *Id.* at 25362-63.

[13] *Id.* at 25363.

[14] 75 FR at 25362 and n. 64

[15] 75 FR at 25632/3.

[16] *See* 75 FR at 25354

[17] 74 Fed. Reg. at 14370 (Mar. 30, 2009).

Chapter 3: Technologies Considered in the Agencies' Analysis

This Chapter of the joint TSD describes the technologies NHTSA and EPA evaluated as potential inputs in their respective models and provides estimates of the technologies' costs, effectiveness and availability. This Chapter also describes, in general terms, how the agencies use these inputs in their respective models.

The agencies assume, in this analysis, that manufacturers will add a variety of technologies to each of their vehicle model platforms in order to improve their fuel economy and GHG performance. In order to evaluate CAFE and GHG standards and regulatory alternatives, it is essential to understand what is feasible within the timeframe of the final rule. Determining the technological feasibility of the MYs 2017-2025 standards requires a thorough study of the technologies available to the manufacturers during that timeframe. This chapter includes an assessment of the cost, effectiveness, and the availability, development time, and manufacturability of the technologies within either the normal redesign periods of a vehicle line or in the design of a new vehicle. As we describe below, when a technology can be applied can affect the costs as well as the technology penetration rates (or phase-in caps) that are assumed in the analysis.

The agencies considered technologies in many categories that manufacturers could use to improve the fuel economy and reduce CO_2 emissions of their vehicles during the MYs 2017-2025 timeframe. Many of the technologies described in this chapter are available today, are well known, and could be incorporated into vehicles once product development decisions are made. These are "nearer-term" technologies and are identical or very similar to those considered in the MYs 2012-2016 final rule analysis (of course, many of these technologies will likely be applied to the light-duty fleet in order to achieve the 2012-2016 CAFE and GHG standards; such technologies would be part of the 2016 reference case for this analysis[a]). Other technologies considered may not currently be in production, but are under development and are expected to be in production in the next five to ten years. Examples of these technologies are downsized and turbocharged engines operating at combustion pressures even higher than today's turbocharged engines, and an emerging hybrid architecture mated with an 8 speed dual clutch transmission (DCT)—a combination that is not available today. These are technologies which the agencies believe can, for the most part, be applied both to cars and trucks, and which are expected to achieve significant improvements in fuel economy and reductions in CO_2 emissions at reasonable costs in the MYs 2017 to 2025 timeframe. The agencies note that we did not consider in our analysis technologies that are currently in an initial stage of research because of the uncertainties involved in estimating their costs and effectiveness and in assessing whether the technologies will be ready to implement at significant penetration rates during the timeframe of the MY 2017-2025 standards. Examples

[a] The technologies in the 2016 reference fleet are projections made by EPA's OMEGA model and NHTSA's CAFE model respectively. Some technologies may be significantly represented in this reference fleet and these details can be found in each agency's respective RIAs.

of such technologies would be camless valve actuation and fuel cell vehicles.[b] The agencies acknowledge that due to the relatively long period between the date of this final rule and the timeframe of the MY 2017-2025 standards, the possibility exists that new and innovative technologies not considered in this analysis will make their way into the fleet (perhaps even in significant numbers). The agencies plan to assess these technologies afresh, along with all of the technologies considered in this final rule, as part of our mid-term evaluation.

3.1 What Technologies did the agencies consider for the final 2017-2025 standards?

The technologies considered for this final rulemaking (FRM) analysis by NHTSA and EPA are briefly described below. They fit generally into five broad categories: engine, transmission, vehicle, electrification/accessory, and hybrid technologies. A more detailed description of each technology, and the technology's costs and effectiveness, is described in greater detail in section 3.4 of this TSD.

Types of engine technologies applied in this FRM analysis, consistent with the proposal, analysis to improve fuel economy and reduce CO_2 emissions include the following:

- *Low-friction lubricants* – low viscosity and advanced low friction lubricants oils are now available with improved performance and better lubrication.
- *Reduction of engine friction losses* – can be achieved through low-tension piston rings, roller cam followers, improved material coatings, more optimal thermal management, piston surface treatments, and other improvements in the design of engine components and subsystems that improve engine operation.
- *Second level of low-friction lubricants and engine friction reduction* – As technologies advance between now and the rulemaking timeframe, there will be further developments enabling lower viscosity and lower friction lubricants and more engine friction reduction technologies available.
- *Cylinder deactivation* – deactivates the intake and exhaust valves and prevents fuel injection into some cylinders during light-load operation. The engine runs temporarily as though it were a smaller engine which substantially reduces pumping losses.
- *Variable valve timing* – alters the timing or phase of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control residual gases.

[b] Fuel cell vehicles may be especially useful in lieu of full battery electric technology for the larger trucks. However, the agencies are not including this technology in the final rule due to the maturity level of the technology.

- *Discrete variable valve lift* – increases efficiency by optimizing air flow over a broader range of engine operation which reduces pumping losses. Accomplished by controlled switching between two or more cam profile lobe heights.

- *Continuous variable valve lift* – is an electromechanically controlled system in which cam period and phasing is changed as lift height is controlled. This yields a wide range of performance optimization and volumetric efficiency, including enabling the engine to be valve throttled.

- *Stoichiometric gasoline direct-injection technology* – injects fuel at high pressure directly into the combustion chamber to improve cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency.

- *Turbocharging and downsizing* – increases the available airflow and specific power level, allowing a reduced engine size while maintaining performance. This reduces pumping losses at lighter loads in comparison to a larger engine. In this FRM, the agencies considered three levels of boosting, 18 bar brake mean effective pressure (BMEP), 24 bar BMEP and 27 bar BMEP, as well as four levels of downsizing, from I4 to smaller I4 or I3, from V6 to I4 and from V8 to V6 and I4. 18 bar BMEP is applied with 33 percent downsizing, 24 bar BMEP is applied with 50 percent downsizing and 27 bar BMEP is applied with 56 percent downsizing. To achieve the same level of torque when downsizing the displacement of an engine by 50 percent, approximately double the manifold absolute pressure (2 bar) is required. Accordingly, with 56 percent downsizing, the manifold absolute pressure range increases up to 2.3 bar. Ricardo states in their 2011 vehicle simulation project report that advanced engines in the 2020–2025 timeframe can be expected to have advanced boosting systems that increase the pressure of the intake charge up to 3 bar[1]. Refer to Section 3.3.1.2.24.2 for examples of Ricardo-modeled displacements used for turbocharged and downsized engines in each vehicle class.

- *Exhaust-gas recirculation boost* – increases the exhaust-gas recirculation used in the combustion process to increase thermal efficiency and reduce pumping losses. Levels of exhaust gas recirculation approach 25% by volume in the highly boosted engines modeled by Ricardo (this, in turn raises the boost requirement by approximately 25%). This technology is only applied to 24 bar and 27 bar BMEP engines in this FRM.

- *Diesel engines* – have several characteristics that give superior fuel efficiency, including reduced pumping losses due to lack of (or greatly reduced) throttling, and a combustion cycle that operates at a higher compression ratio, with a very lean air/fuel mixture, than an equivalent-performance gasoline engine. This technology requires additional enablers, such as NO_x trap catalyst after-treatment or selective catalytic reduction NO_x after-treatment.

Types of transmission technologies applied in this FRM, consistent with the proposal, include:

- *Improved automatic transmission controls* – optimizes shift schedule to maximize fuel efficiency under wide ranging conditions, and minimizes losses associated with torque converter slip through lock-up or modulation.
- *Six- and seven-speed automatic transmissions* – the gear ratio spacing and transmission ratio are optimized to enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions.
- *Dual clutch transmission (DCT)* - are similar to a manual transmission, but the vehicle controls shifting and launch functions. A dual-clutch automated shift manual transmission uses separate clutches for even-numbered and odd-numbered gears, so the next expected gear is pre-selected, which allows for faster, smoother shifting.
- *Eight-speed automatic transmissions* – the transmission gear ratios are optimized to enable the engine to operate in a more efficient operating range over a broader range of vehicle operating conditions. This technology is applied after 2016.
- *Shift Optimization* – tries to keep the engine operating near its most efficient point for a given power demand. The shift controller emulates a traditional Continuously Variable Transmission by selecting the best gear ratio for fuel economy at a given required vehicle power level to take full advantage of high BMEP engines.
- *Manual 6-speed transmission* – offers an additional gear ratio, often with a higher overdrive gear ratio, than a 5-speed manual transmission.
- *High Efficiency Gearbox (automatic, DCT or manual)* – continuous improvement in seals, bearings and clutches, super finishing of gearbox parts, and development in the area of lubrication, all aimed at reducing frictional and other parasitic load in the system for an automatic, DCT or manual type transmission.

Types of vehicle technologies applied in this FRM analysis, consistent with the proposal, analysis include:

- *Low-rolling-resistance tires* – have characteristics that reduce frictional losses associated with the energy dissipated in the deformation of the tires under load, thereby reducing the energy needed to move the vehicle. There are two levels of rolling resistance reduction considered in this FRM analysis targeting at 10 percent and 20 percent rolling resistance reduction respectively.
- *Low-drag brakes* – reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotors.
- *Front or secondary axle disconnect for four-wheel drive systems* – provides a torque distribution disconnect between front and rear axles when torque is not required for the non-driving axle. This results in the reduction of associated parasitic energy losses.

- *Aerodynamic drag reduction* – is achieved by changing vehicle shape or reducing frontal area, including skirts, air dams, underbody covers, and more aerodynamic side view mirrors. There are two levels of aerodynamic drag reduction considered in this FRM analysis targeting 10 percent and 20 percent aerodynamic drag reduction respectively.
- *Mass reduction*– Mass reduction encompasses a variety of techniques ranging from improved design and better component integration to application of lighter and higher-strength materials. Mass reduction can lead to collateral fuel economy and GHG benefits due to downsized engines and/or ancillary systems (transmission, steering, brakes, suspension, etc.). The maximum mass reduction level considered in this FRM is 20 percent.

Types of electrification/accessory and hybrid technologies applied in this FRM include:

- *Electric power steering (EPS) and electro-hydraulic power steering (EHPS)* – is an electrically-assisted steering system that has advantages over traditional hydraulic power steering because it replaces a continuously operated hydraulic pump, thereby reducing parasitic losses from the accessory drive.
- *Improved accessories (IACC)* – There are two levels of IACC applied in this FRM analysis, consistent with the proposal. The first level may include high efficiency alternators, electrically driven (i.e., on-demand) water pumps and cooling systems. This excludes other electrical accessories such as electric oil pumps and electrically driven air conditioner compressors. The second level of IACC includes alternator regenerative braking on top of what are included in the first level of IACC.
- *Air Conditioner Systems* – These technologies include improved hoses, connectors and seals for leakage control. They also include improved compressors, expansion valves, heat exchangers and the control of these components for the purposes of improving tailpipe CO_2 emissions and fuel economy when the A/C is operating. These technologies are covered separately in Chapter 5 of this joint TSD.
- *12-volt Stop-start* – also known as idle-stop or 12V micro hybrid and commonly implemented as a 12-volt belt-driven integrated starter-generator, this is the most basic hybrid system that facilitates idle-stop capability. Along with other enablers, this system replaces a common alternator with an enhanced power starter-alternator, both belt driven, and a revised accessory drive system.
- *Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG)* – sometimes referred to as a mild hybrid, BISG provides idle-stop capability and launch assistance and uses a high voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the motor, inverter, and battery wiring harnesses. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency belt-driven starter-

alternator which can recover braking energy while the vehicle slows down (regenerative braking). An example of a BISG system is the GM eAssist introduced in MY 2012. This technology was not included in the analysis for the proposal because we had incomplete information on the technology at that time. Since the proposal, the agencies have obtained better data on the costs and effectiveness of this technology (see 3.4.3.5 of this joint TSD). Therefore, the agencies have revised their technical analysis on both and found that the technology is now competitive with the others in the CAFE model technology decision trees and EPA's technology packages. Further, this technology has been used for "game changing" credit for pick-up trucks and can act as a bridge technology for strong hybrid. For these reasons, the technology is now included in the analysis.

- *P2 Hybrid* – P2 hybrid is a hybrid technology that uses a transmission integrated electric motor placed between the engine and a gearbox or CVT, with a wet or dry separation clutch which is used to decouple the motor/transmission from the engine. In addition, a P2 Hybrid would typically be equipped with a larger electric machine than a mild hybrid system but smaller than a power-split or 2-mode hybrid architecture. Disengaging the clutch allows all-electric operation and more efficient brake-energy recovery. Engaging the clutch allows efficient coupling of the engine and electric motor and based on simulation, when combined with a DCT transmission, provides similar or improved fuel efficiency to other strong hybrid systems with reduced cost.

- *Plug-in hybrid electric vehicles (PHEV)* – are hybrid electric vehicles with the means to charge their battery packs from an outside source of electricity (usually the electric grid). These vehicles have larger battery packs than non-plug-in hybrid electric vehicles with more energy storage and a greater capability to be discharged. They also use a control system that allows the battery pack to be substantially depleted under electric-only or blended mechanical/electric operation, allowing for reduced fuel use during "charge depleting" operation.

- *Electric vehicles (EV)* – are vehicles with all-electric drive and with vehicle systems powered by energy-optimized batteries charged primarily from grid electricity. EVs with 75 mile, 100 mile and 150 mile ranges have been included as potential technologies.

Types of accessory/hybridization/electrification technologies discussed but not applied in this FRM analysis, consistent with the proposal, include:

- *Integrated Motor Assist (IMA)/Crank integrated starter generator (CISG)* – provides idle-stop capability and uses a high voltage battery with increased energy capacity over typical automotive batteries. The higher system voltage allows the use of a smaller, more powerful electric motor and reduces the weight of the wiring harness. This system replaces a standard alternator with an enhanced power, higher voltage and higher efficiency starter-alternator that is crankshaft mounted and can recover braking energy while the vehicle slows down (regenerative braking). The IMA technology is not included as an enabling technology in this analysis as the industry trends toward more cost effective hybrid configurations, although it is included as a baseline technology because it exists in the baseline fleet.

- *Power-split Hybrid (PSHEV)* – is a hybrid electric drive system that replaces the traditional transmission with a single planetary gearset and two motor/generators. The smaller motor/generator uses the engine to either charge the battery or supply additional power to the drive motor. The second, more powerful motor/generator is permanently connected to the vehicle's final drive and always turns with the wheels, as well as providing regenerative braking capability. The planetary gearset splits engine power between the first motor/generator and the output shaft to either charge the battery or supply power to the wheels. The power-split hybrid technology is not included as an enabling technology in this analysis as the industry is expected to trend toward more cost-effective hybrid configurations, although it is included as a baseline technology because it exists in the baseline fleet.

- *2-Mode Hybrid (2MHEV)* – is a hybrid electric drive system that uses an adaptation of a conventional stepped-ratio automatic transmission by replacing some of the transmission clutches with two electric motors that control the ratio of engine speed to vehicle speed, while clutches allow the motors to be bypassed. This improves both the transmission torque capacity for heavy-duty applications and reduces fuel consumption and CO_2 emissions at highway speeds relative to other types of hybrid electric drive systems. The 2-mode hybrid technology is not included as an enabling technology in this analysis as the industry is expected to trend toward more cost effective hybrid configurations, although it is included as a baseline technology because it exists in the baseline fleet.

3.2 How did the agencies determine the costs of each of these technologies?

3.2.1 Direct Costs[c]

3.2.1.1 Costs from Tear-down Studies

There are a number of technologies in this analysis that have been cost using the rigorous tear-down method described in this section. As a general matter, the agencies believe that the best method to derive technology cost estimates is to conduct studies involving tear-down and analysis of actual vehicle components. A "tear-down" involves breaking down a technology into its fundamental parts and manufacturing processes by completely disassembling actual vehicles and vehicle subsystems and precisely determining

[c] Note that only battery pack and non-battery costs for HEVs, EVs and PHEVs have changed since proposal. All other direct costs are unchanged except for adjustments from 2009 to 2010 dollars. Battery pack and non-battery cost changes are detailed in Section 3.4.3.6.

what is required for its production. The result of the tear-down is a "bill of materials" for each and every part of the vehicle or vehicle subsystem. This tear-down method of costing technologies is often used by manufacturers to benchmark their products against competitive products. Historically, vehicle and vehicle component tear-down has not been done on a large scale by researchers and regulators due to the expense required for such studies. While tear-down studies are highly accurate at costing technologies for the year in which the study is intended, their accuracy, like that of all cost projections, may diminish over time as costs are extrapolated further into the future because of uncertainties in predicting commodities (and raw material) prices, labor rates, and manufacturing practices. The projected costs may be higher or lower than predicted.

Over the past several years, EPA has contracted with FEV, Inc. and its subcontractor Munro & Associates to conduct tear-down cost studies for a number of key technologies evaluated by the agencies in assessing the feasibility of future GHG and CAFE standards. The analysis methodology included procedures to scale the tear-down results to smaller and larger vehicles, and also to different technology configurations. FEV's methodology was documented in a report published as part of the MY 2012-2016 rulemaking process, detailing the costing of the first tear-down conducted in this work (#1 in the below list).[2] This report was peer reviewed by experts in the industry and revised by FEV in response to the peer review comments.[3] Subsequent tear-down studies (#2-5 in the below list) were documented in follow-up FEV reports made available in the public docket for the MY 2012-2016 rulemaking.[4]

Since then, FEV's work under this contract has continued. Additional cost studies have been completed for mild hybrid technology and are available for public review.[5] The most extensive study, performed after the MY 2012-2016 Final Rule, involved whole-vehicle tear-downs of a 2010 Ford Fusion power-split hybrid and a conventional 2010 Ford Fusion. (The latter served as a baseline vehicle for comparison.) In addition to providing power-split HEV costs, the results for individual components in these vehicles were subsequently used to cost another hybrid technology, the P2 hybrid, which employs similar hardware. This approach to costing P2 hybrids was undertaken because P2 HEVs were not yet in volume production at the time of hardware procurement for tear-down. Finally, an automotive lithium-polymer battery was torn down and costed to provide supplemental battery costing information to that associated with the NiMH battery in the Fusion, because we think automakers are moving to Li-ion battery technologies due to the higher energy and power density of these batteries. This HEV cost work, including the extension of results to P2 HEVs, has been extensively documented in a new report prepared by FEV.[6] Because of the complexity and comprehensive scope of this HEV analysis, EPA commissioned a separate peer review focused exclusively on the new tear down costs developed for the HEV analysis. Reviewer comments generally supported FEV's methodology and results, while including a number of suggestions for improvement, many of which were subsequently incorporated into FEV's analysis and final report. The peer review comments and responses are available in the rulemaking docket.[d,e] Over the course of this contract between EPA and FEV, FEV performed teardown-based studies on the technologies listed below. These completed studies provide a thorough evaluation of the new technologies' costs relative to their baseline (or replaced) technologies.

1. Stoichiometric gasoline direct injection (SGDI) and turbocharging with engine downsizing (T-DS) on a DOHC (dual overhead cam) I4 engine, replacing a conventional DOHC I4 engine.
2. SGDI and T-DS on a SOHC (single overhead cam) on a V6 engine, replacing a conventional 3-valve/cylinder SOHC V8 engine.
3. SGDI and T-DS on a DOHC I4 engine, replacing a DOHC V6 engine.
4. 6-speed automatic transmission (AT), replacing a 5-speed AT.
5. 6-speed wet dual clutch transmission (DCT) replacing a 6-speed AT.
6. 8-speed AT replacing a 6-speed AT.
7. 8-speed DCT replacing a 6-speed DCT.
8. Power-split hybrid (Ford Fusion with I4 engine) compared to a conventional vehicle (Ford Fusion with V6). The results from this tear-down were extended to address P2 hybrids. In addition, costs from individual components in this tear-down study were used by the agencies in developing cost estimates for PHEVs and EVs.
9. Mild hybrid with stop-start technology (Saturn Vue with I4 engine), replacing a conventional I4 engine.
10. Fiat Multi-Air engine technology. (Although results from this cost study are included in the rulemaking docket, they were not used by the agencies in this rulemaking's technical analyses because the technology is under a very recently awarded patent and we have chosen not to base our analyses on its widespread use across the industry in the 2017-2025 timeframe.)

In addition, FEV and EPA extrapolated the engine downsizing costs for the following scenarios that were based on the above study cases:

- Downsizing a SOHC 2 valve/cylinder V8 engine to a DOHC V6.
- Downsizing a DOHC V8 to a DOHC V6.
- Downsizing a SOHC V6 engine to a DOHC 4 cylinder engine.
- Downsizing a DOHC 4 cylinder engine to a DOHC 3 cylinder engine.

The agencies have relied on the findings of FEV for estimating the cost of the technologies covered by the tear-down studies. However, we note that FEV based their costs on the assumption that these technologies would be mature when produced in large volumes

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[d] ICF, "Peer Review of FEV Inc. Report Light Duty Technology Cost Analysis, Power-Split and P2 Hybrid Electric Vehicle Case Studies", EPA-420-R-11-016, November 2011.

[e] FEV and EPA, "FEV Inc. Report 'Light Duty Technology Cost Analysis, Power-Split and P2 Hybrid Electric Vehicle Case Studies', Peer Review Report – Response to Comments Document", EPA-420-R-11-017, November 2011.

(450,000 units or more for each component or subsystem). If manufacturers are not able to employ the technology at the volumes assumed in the FEV analysis with fully learned costs, then the costs for each of these technologies would be expected to be higher. There is also the potential for stranded capital[f] if technologies are introduced too rapidly for some indirect costs to be fully recovered. While the agencies consider the FEV tear-down analysis results to be generally valid for the 2017-2025 timeframe for fully mature, high sales volumes, we have had FEV perform supplemental analysis to consider potential stranded capital costs, and have included these in our primary analyses of program costs. The issue of stranded capital is discussed in detail in Section 3.2.2.3 of this TSD.

3.2.1.2 Costs of HEV, PHEV, EV, and FCEVs

The agencies have also reconsidered the costs for HEVs, PHEVs, EVs, and FCEVs since the MY 2012-2016 rulemaking and the Technical Assessment Report (TAR) as the result of two issues. The first issue is that electrified vehicle technologies are developing rapidly and we sought to capture the results from the most recent analyses. The second issue is that the analysis for the MYs 2012-2016 final rule employed a single $/kWh ($ per kilowatt-hour) estimate, and did not consider the specific vehicle and technology application for the battery when we estimated the cost of the battery.[g] Specifically, batteries used in HEVs (high power density applications) versus EVs (high energy density applications) need to be considered appropriately to reflect the design differences, the chemical material usage differences, and the differences in cost per kWh as the power to energy ratio of the battery changes for different applications. To address these issues for this final rule, consistent with the proposal, the agencies have used a battery cost model developed by Argonne National Laboratory (ANL) for the Vehicle Technologies Program of the U.S. Department of Energy (DoE) Office of Energy Efficiency and Renewable Energy.[7] The model developed by ANL allows users to estimate unique battery pack costs using user customized input sets for different types of electrified powertrains, such as strong hybrid, PHEV and EV. Since the publication of the TAR, ANL's battery cost model has been peer-reviewed and ANL has updated the model to incorporate suggestions from peer-reviewers.[8] Further updates have been made to the model since the NPRM and this newly updated model is used in this FRM analysis.[9] We discuss our updated battery costs in section in Section 3.4.3.9. As done in the proposal, the agencies developed costs and effectiveness values for the mild and P2 HEV configuration, two different all-electric mileage ranges for PHEVs (20 and 40 in-use miles) and three different mileage ranges for EVs (75, 100 and 150 in-use miles). Details regarding these vehicle technologies are discussed in sections 3.4.3.6.4 and 3.4.3.6.5.

[f] The potential for stranded capital occurs when manufacturing equipment and facilities cannot be used in the production of a new technology.
[g] However, we believe that this had little impact on the results of the cost analyses in support of the MYs 2012-2016 final rule, as the agencies projected that the standards could be met with an increase of less than 2 percent penetration of hybrid technology and no increase in plug-in or full electric vehicle technology.

3.2.1.3 Direct Manufacturing Costs Used in the Rulemaking Analysis

Building on the MYs 2012-2016 final rule, for the NPRM analysis, the agencies took a fresh look at technology cost and effectiveness values. For this final rule analysis, the direct manufacturing costs employed in the NPRM have been largely retained, although they were updated to 2010$, and revisions were made to the costs of Li-ion batteries. The battery costs have been updated for the final rule using the latest ANL BatPaC model as discussed above. For costs, the agencies considered both the direct or "piece" costs and indirect costs of individual components of technologies. For the direct costs that were not developed through the FEV tear-down studies, the agencies generally followed a bill of materials (BOM) approach. A bill of materials, in a general sense, is a list of components that make up a system—in this case, an item of fuel economy-improving technology. In order to determine what a system costs, one of the first steps is to determine its components and what they cost.

NHTSA and EPA estimated these components and their costs based on a number of sources for cost-related information. The objective was to use those sources of information considered to be most credible for projecting the costs of individual vehicle technologies. For those cost estimates that are fundamentally unchanged since the 2012-2016 final rule and/or the 2010 TAR (we make note of these in Section 3.4, below), we have a full description of the sources used in Chapter 3 of the final joint TSD supporting that rule.[10,11] For those costs that have been updated since those analyses (e.g., battery pack cost, costs based on more recent tear down analyses, etc.), we note their sources in Section 3.4, below. We have also considered input from manufacturers and suppliers gathered either through meetings following the 2010 TAR or in comment submitted in response to the 2010 TAR, some of which cannot be shared publicly in detailed form but, where used, we make note of it while protecting its confidentiality. In this final rule analysis, the agencies have not updated the costs based on any confidential information. Note that a summary of comments on the 2010 TAR, with the agencies' responses, was published as a "Supplemental Notice of Intent" in December of 2010.[12] As discussed throughout this chapter, the agencies have reviewed, revalidated or updated cost estimates for individual components based on the latest information available.

Once costs were determined, they were adjusted to ensure that they were all expressed in 2010 dollars (the NPRM was in 2009 dollars) using the GDP price deflator as described in section 3.2.4.[h] Indirect costs were accounted for using the ICM approach developed by EPA and explained below. NHTSA and EPA also considered how costs should be adjusted to reflect manufacturer learning as discussed below. Additionally, costs were adjusted by modifying or scaling content assumptions to account for differences across the range of vehicle sizes and functional requirements, and the associated material cost impacts were adjusted to account for the revised content, although these adjustments were different for each agency due to the different vehicle subclasses used in their respective models.

[h] The conversion to 2010 dollars has very little impact on costs (the conversion factor to convert from 2009 to 2010 dollars is 1.01).

3.2.2 Indirect Costs[i]

3.2.2.1 Indirect Cost Multiplier Changes since the 2012-2016 FRM and 2010 TAR

As discussed in greater detail below, the agencies have revised the markups used to estimate indirect costs. The first change was to normalize the ICM values to be consistent with the historical average retail price equivalent (RPE) of 1.5, rather than the single year that the RTI study examined. This was done by applying a factor of .5/.46 to all indirect cost elements. The second change was to re-consider the markup factors and the data used to generate them. The result on this new thinking is to increase the markup in all cases. The final change is the way in which the ICM factors are applied. In previous analyses ICMs were applied to the learned value of direct costs. However, since learning influences direct costs only, the agencies were concerned that this could overstate the impact of learning on total costs. Indirect costs are thus now established based on the initial value of direct costs and held constant until the long-term ICM is applied. This is done for all ICM factors except warranties, which are influenced by the learned value of direct costs.

3.2.2.2 Cost markups to account for indirect costs

To produce a unit of output, auto manufacturers incur direct and indirect costs. Direct costs include the cost of materials and labor costs. Indirect costs may be related to production (such as research and development [R&D]), corporate operations (such as salaries, pensions, and health care costs for corporate staff), or selling (such as transportation, dealer support, and marketing). Indirect costs are generally recovered by allocating a share of the costs to each unit of goods sold. Although it is possible to account for direct costs allocated to each unit of goods sold, it is more challenging to account for indirect costs allocated to a unit of goods sold. To make a cost analysis process more feasible, markup factors, which relate total indirect costs to total direct costs, have been developed. These factors are often referred to as retail price equivalent (RPE) multipliers.

Cost analysts and regulatory agencies including EPA and NHTSA have frequently used these multipliers to estimate the resultant impact on costs associated with manufacturers' responses to regulatory requirements. The best approach to determining the impact of changes in direct manufacturing costs on a manufacturer's indirect costs would be to actually estimate the cost impact on each indirect cost element. However, doing this within the constraints of an agency's time or budget is not always feasible, and the technical, financial, and accounting information to carry out such an analysis may simply be unavailable.

RPE multipliers provide, at an aggregate level, the relative shares of revenues (Revenue = Direct Costs + Indirect Costs + Net Income) to direct manufacturing costs. Using RPE multipliers implicitly assumes that incremental changes in direct manufacturing costs produce common incremental changes in all indirect cost contributors as well as net income.

[i] Note that our approach to estimating indirect costs remains unchanged since the proposal.

A concern in using the RPE multiplier in cost analysis for new technologies added in response to regulatory requirements is that the indirect costs of vehicle modifications are not likely to be the same for different technologies. For example, less complex technologies could require fewer R&D efforts or less warranty coverage than more complex technologies. In addition, some simple technological adjustments may, for example, have no effect on the number of corporate personnel and the indirect costs attributable to those personnel. The use of RPEs, with their assumption that all technologies have the same proportion of indirect costs, is likely to overestimate the costs of less complex technologies and underestimate the costs of more complex technologies.

To address this concern, EPA has developed modified multipliers. These multipliers are referred to as indirect cost multipliers (ICMs). In contrast to RPE multipliers, ICMs assign unique incremental changes to each indirect cost contributor

$$ICM = (\text{direct cost} + \text{adjusted indirect cost} + \text{profit})/(\text{direct cost})$$

Developing the ICMs from the RPE multipliers requires developing adjustment factors based on the complexity of the technology and the time frame under consideration. This methodology was used in the cost estimation for the MYs 2012-2016 final rule. The ICMs were developed in a peer-reviewed report from RTI International and were subsequently discussed in a peer-reviewed journal article.[13] Note that the cost of capital (reflected in profit) is included because of the assumption implicit in ICMs (and RPEs) that capital costs are proportional to direct costs, and businesses need to be able to earn returns on their investments. The capital costs are those associated with the incremental costs of the new technologies.

As noted above, for the analysis supporting this final rulemaking, consistent with the proposal, the agencies are again using the ICM approach but have made some changes to both the ICM factors and to the method of applying those factors to arrive at a final cost estimate. The first of these changes was done in response to continued thinking among the EPA-NHTSA team about how past ICMs have been developed and what are the most appropriate data sources to rely upon in determining the appropriate ICMs. The second change has been done both due to staff concerns and public feedback suggesting that the agencies were inappropriately applying learning effects to indirect costs via the multiplicative approach to applying the ICMs.

Regarding the first change – to the ICM factors themselves – a little background must first be provided. In the original work done under contract to EPA by RTI International,[14] EPA staff with extensive experience in the auto industry had undertaken a consensus approach to determining the impact of specific technology changes on the indirect costs of a company. Subsequent to that effort, EPA staff, again with extensive experience in the auto industry, conducted a blind survey to make this determination on a different set of technology changes. This subsequent effort, referred to by EPA as a modified-Delphi approach, resulted in slightly different ICM determinations. This effort is detailed in a memorandum contained in the docket for this rule.[15] Upon completing this effort, the EPA team determined that the original RTI values should be averaged with the modified-Delphi values to arrive at the final

ICMs for low and medium complexity technologies and that the original RTI values would be used for high complexity level 1 while the modified-Delphi values would be used for high complexity level 2. These final ICMs as described were used in the MYs 2012-2016 light-duty GHG/CAFE rulemaking.

More recently, EPA and NHTSA decided that the original light-duty RTI values, because of the technologies considered for low and medium complexity, should no longer be used and that we should rely solely on the modified-Delphi values for these complexity levels. The original light-duty RTI study used low rolling resistance tires as a low complexity technology example and a dual clutch transmission as a medium complexity technology. Upon further thought, the technologies considered for the modified Delphi values (passive aerodynamic improvements for low complexity and turbocharging with downsizing for medium complexity) were considered to better represent the example technologies. As a result, the modified-Delphi values became the working ICMs for low and medium complexity rather than averaging those values with the original RTI report values. NHTSA and EPA staff also re-examined the technology complexity categories that were assigned to each light-duty technology and modified these assignments to better reflect the technologies that are now used as proxies to determine each category's ICM value.

A secondary-level change was also made as part of this ICM recalculation to the light-duty ICMs. That change was to revise upward the RPE level reported in the original RTI report from an original value of 1.46 to 1.5 to reflect the long term average RPE. The original RTI study was based on 2007 data. However, an analysis of historical RPE data indicates that, although there is year to year variation, the average RPE has remained roughly 1.5. ICMs will be applied to future year's data and therefore NHTSA and EPA staff believe that it would be appropriate to base ICMs on the historical average rather than a single year's result. Therefore, ICMs in this final rulemaking, consistent with the proposal, were adjusted to reflect this average level. As a result, the High 1 and High 2 ICMs have also changed.

Table 3-1 shows both the ICM values used in the MYs 2012-2016 final rule and the new ICM values used for the analysis supporting these final rules. Near term values account for differences in the levels of R&D, tooling, and other indirect costs that will be incurred. Once the program has been fully implemented, some of the indirect costs will no longer be attributable to the standards and, as such, a lower ICM factor is applied to direct costs.

Table 3-1 Indirect Cost Multipliers Used in this Analysis[a]

	2012-2016 Rule		This Final rule	
Complexity	Near term	Long term	Near term	Long term
Low	1.17	1.13	1.24	1.19
Medium	1.31	1.19	1.39	1.29
High1	1.51	1.32	1.56	1.35
High2	1.70	1.45	1.77	1.50

[a] Rogozhin, A., et. al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009); "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," Helfand, G., and Sherwood, T., Memorandum dated August 2009; "Heavy Duty Truck Retail Price Equivalent and Indirect Cost

Multipliers," Draft Report prepared by RTI International and Transportation Research Institute, University of Michigan, July 2010

The second change made to the ICMs has to do with the way in which they are applied. To date, we have applied the ICMs, as done in any analysis that relied on RPEs, as a pure multiplicative factor. This way, a direct manufacturing cost of, say, $100 would be multiplied by an ICM of 1.24 to arrive at a marked up technology cost of $124. However, as learning effects (discussed below) are applied to the direct manufacturing cost, the indirect costs are also reduced accordingly. Therefore, in year two the $100 direct manufacturing cost might reduce to $97, and the marked up cost would become $120 ($97 x 1.24). As a result, indirect costs would be reduced from $24 to $20. Given that indirect costs cover many things such as facility-related costs, electricity, etc., it is perhaps not appropriate to apply the ICM to the learned direct costs, at least not for those indirect cost elements unlikely to change with learning. The EPA-NHTSA team believes that it is appropriate to allow only warranty costs to decrease with learning, since warranty costs are tied to direct manufacturing costs (since warranty typically involves replacement of actual parts which should be less costly with learning). The remaining elements of the indirect costs should remain constant year-over-year, at least until some of those indirect costs are no longer attributable to the rulemaking effort that imposed them (such as R&D).

As a result, the ICM calculation has become more complex with the analysis supporting this final rule, consistent with the proposal. We must first establish the year in which the direct manufacturing costs are considered "valid." For example, a cost estimate might be considered valid today, or perhaps not until high volume production is reached—which will not occur until MY 2015 or later. That year is known as the base year for the estimated cost. That cost is the cost used to determine the "non-warranty" portion of the indirect costs. For example, the non-warranty portion of the medium complexity ICM in the short-term is 0.343 (the warranty versus non-warranty portions of the ICMs are shown in Table 3-2).

For the dual cam phasing (DCP) technology on an I4 engine we have estimated a direct manufacturing cost of $70 in MY 2015. So the non-warranty portion of the indirect costs would be $24.01 ($70 x 0.343). This value would be added to the learned direct manufacturing cost for each year through 2018, the last year of short term indirect costs. Beginning in 2019, when long-term indirect costs begin, the additive factor would become $18.13 ($70 x 0.259). Additionally, the $70 cost in 2015 would become $67.90 in MY 2016 due to learning ($70 x (1-3%)). So, while the warranty portion of the indirect costs would be $3.15 ($70 x 0.045) in 2015, indirect costs would decrease to $3.06 ($67.90 x 0.045) in 2016 as warranty costs decrease with learning. The resultant indirect costs for the DCP-I4 technology would be $27.16 ($24.01+$3.15) in MY 2015 and $27.07 ($24.01+$3.06) in MY2016, and so on for subsequent years.

Table 3-2 Warranty and Non-Warranty Portions of ICMs

	Near term		Long term	
Complexity	Warranty	Non-warranty	Warranty	Non-warranty
Low	0.012	0.230	0.005	0.187

Medium	0.045	0.343	0.031	0.259
High1	0.065	0.499	0.032	0.314
High2	0.074	0.696	0.049	0.448

There is some level of uncertainty surrounding both the ICM and RPE markup factors. The ICM estimates used in this final rule, consistent with the proposal, group all technologies into three broad categories and treat them as if individual technologies within each of the three categories (low, medium, and high complexity) will have exactly the same ratio of indirect costs to direct costs. This simplification means it is likely that the direct cost for some technologies within a category will be higher and some lower than the estimate for the category in general. Additionally, the ICM estimates were developed using adjustment factors developed in two separate occasions: the first, a consensus process, was reported in the RTI report; the second, a modified Delphi method, was conducted separately and reported in an EPA memorandum. Both these panels were composed of EPA staff members with previous background in the automobile industry; the memberships of the two panels overlapped but were not the same. The panels evaluated each element of the industry's RPE estimates and estimated the degree to which those elements would be expected to change in proportion to changes in direct manufacturing costs. The method and the estimates in the RTI report were peer reviewed by three industry experts and subsequently by reviewers for the International Journal of Production Economics.[16] However, the ICM estimates have not yet been validated through a direct accounting of actual indirect costs for individual technologies. RPEs themselves are also inherently difficult to estimate because the accounting statements of manufacturers do not neatly categorize all cost elements as either direct or indirect costs. Hence, each researcher developing an RPE estimate must apply a certain amount of judgment to the allocation of the costs. Since empirical estimates of ICMs are ultimately derived from the same data used to measure RPEs, this affects both measures. However, the value of RPE has not been measured for specific technologies, or for groups of specific technologies. Thus applying a single average RPE to any given technology by definition overstates costs for very simple technologies, or understates them for advanced technologies.

The International Council on Clean Transportation (ICCT) and the National Automobile Dealers Association (NADA) commented on our use of ICMs. ICCT supported the ICM approach as presented in the proposal, but argued for removal of sensitivity analyses examining RPEs in NHTSA's FRIA. NADA argued that the ICM approach is not valid and should be replaced with an RPE approach. Further, it argued that the RPE factor should be 2x rather than the 1.5x approach that is supported by filings to the Securities and Exchange Commission. We have conducted a thorough analysis of the NADA comments on the RPE vs. ICM approach. We disagree with NADA's arguments for both using the RPE approach and a 2x RPE factor, for the following reasons.

NADA's objections to the ICM approach include:

1. There is no evidence that the RPE method is flawed.
2. The ICMs do not include the total costs of complying with the standards, because it does not include all the costs included in the RPE.

3. The ICMs use a subjective judgment to adjust indirect costs for different technologies, while the RPE uses one value for all components and does not rely on "nearly perfect foreknowledge."
4. The ICMs do not incorporate dealer and OEM profits.

NADA's arguments for the RPE of 2x include:

5. Several scholarly papers support the use of RPEs in the 2.0 range.
6. A case study comparison of the added content of a 1971 Chevrolet Vega and 2011 Cruze shows that an RPE of 2.0 accounts for the change in retail price.

The discussion above provides background on the issue of RPEs and ICMs, and on the agencies' decision to use ICMs to estimate indirect costs for this rulemaking. Our responses here address the specific points raised by NADA.

First, the RPE approach applies the same average indirect cost markup across all technologies in the redesigned vehicle fleet, regardless of the source of the direct cost (i.e. whether a technology is simple or complex; whether the source of the additional cost is a new or a mature technology). The RPE methodology also assumes that an indirect cost is associated with the rule, even if no relation is apparent. For instance, the RPEs (until recent union contract changes) would have included the costs to the domestic auto companies of the health insurance for retired auto workers. Because the rulemaking would not affect the current retiree health care costs, (which account for about 1.5% of the RPE), they are irrelevant to the rulemaking. The ICM approach differs in that it allows indirect costs to vary with the complexity of the technology and the time frame.[17] It is a reasonable assumption that simple technologies are expected to have fewer indirect costs per dollar than complex technologies. For instance, the use of low-rolling-resistance tires, considered by the EPA/NHTSA team to be a low-complexity technology, adds costs, but, because they require significantly less vehicle integration effort than for example, adding a hybrid powertrain would, the additional indirect costs per dollar of direct manufacturing costs may be very low. In contrast, converting a conventional vehicle to a hybrid-electric is a far more complex activity, involving increases in indirect costs such as research and development disproportionate to its direct costs. Shortly after product introduction, indirect costs for components such as warranty and research may be relatively high, but auto makers are expected to be able to reduce the costs of any specific technology over time, as they gain experience with them and, thus, redirect those expenditures to other areas of their choosing.

Second, the ICM approach excludes some costs included in the RPE when those costs are expected not to be affected by the standards. The ICM approach, as discussed above, begins with the RPE and includes all the relevant cost categories. ICMs reflect the indirect costs judged by the EPA panel (see above for further explanation) to be incurred for each technology in response to regulatory imposed changes. Any "omissions", or instances where the ICM carries no costs for a given technology, are cases where the indirect costs are considered by the EPA panel not to be impacted by regulatory imposed changes for that technology. For instance, the costs of switching from a standard tire to a low-rolling-resistance tire (the example of a low-complexity technology in Rogozhin et al. (2009)) are not expected to lead to an increase in transportation costs (i.e., costs for transporting finished vehicles from production site to retail site) because it is not expected to be any more expensive to ship a new vehicle with the new tires than with the old tires.[18]

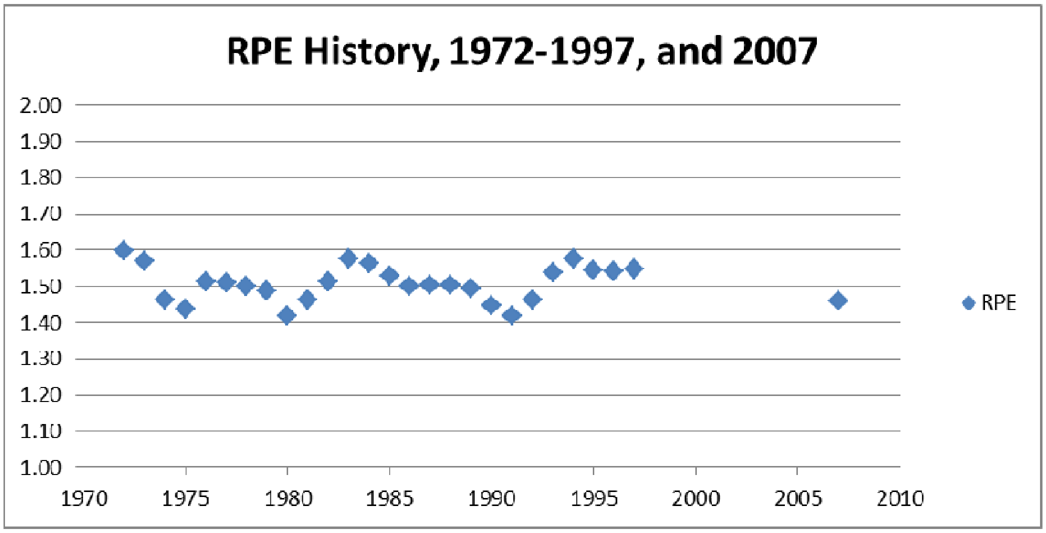
Third, the RPE approach relies on the assumption that applying the average RPE for the vehicle fleet as a whole will produce a reasonable average indirect cost for all technologies in the redesigned vehicle fleet resulting from these standards. The agencies believe that using the professional judgment and expertise of EPA staff with extensive experience in the auto industry provides useful insight into how a given regulation will impact indirect costs and is an improvement over ignoring differences among technologies. The agencies have therefore based their central analyses on the ICM method.

Fourth, it is incorrect that the ICMs do not include profit. Although the initial ICM report reviewed by NRC did not include OEM profit, the ICM approach applied in this rulemaking does incorporate an allowance for profit, at the average corporate profit rate of 6% of sales. The inclusion of profit for the Joint NPRM is discussed in the draft Technical Support Document, and the agencies have included profit as an element of the indirect costs for the final rulemaking as well.[19]

Fifth, the papers cited to support the use of an RPE of 2x are only a subset of the literature. The National Research Council (NRC)[20] discusses the four studies that NADA's Exhibit A cites in its support of an RPE of 2.0. The NRC also notes that NHTSA used an RPE of 1.5 for its MY 2011 fuel economy rule; the NRC in 2002 used an RPE of 1.4, as did the California Air Resources Board; and EPA has used a markup factor of 1.3. The NRC report then discusses work done for the committee itself, doing a detailed analysis of a Honda Accord and a Ford F-150 truck; the former had an RPE of "1.39 to market transaction price and 1.49 to MSRP," and the latter had an RPE of "1.52 for market price and 1.54 for MSRP." Most significantly, the NRC does not recommend an RPE of 2.0. Rather, the NRC recommends, for technologies where the primary manufacturer of the technology is the automotive supply base, an RPE of 1.5, except for hybrid powertrain components from the automotive supply base, where it recommends an RPE of 1.3 due to the inclusion of several indirect costs in their base estimate.[21] Only in the case of technologies where an automotive OEM is the primary manufacturer does the NRC recommend an RPE of 2.0.[j] We note, without specifically commenting on the quality of the studies, that none of the papers NADA cites in support of an RPE of 2x was published in a peer-reviewed journal, and none of the studies claim to have been peer-reviewed. In contrast, the research in Rogozhin et al. (2009) was peer-reviewed twice: as documented in the Peer Review Report, and when it was submitted (and accepted) for publication in the *International Journal of Production Economics*. A full reading of the literature on RPEs thus shows little support for a value of 2x. Further support for an average

[j] Importantly, application of the 2.0s RPE in the "OEM as primary manufacturer" case would be done to a smaller direct cost since the OEM has produced the part in-house and, thus, is not paying the full supplier-level indirect costs that would be included in a part purchased from a supplier. The end result should be a total cost roughly equivalent or less than a 1.5x RPE applied to the supplier-produced part. If not, the manufacturer should probably not produce in-house and should, instead, purchase parts since they would be less costly (all other considerations being equal).

RPE lower than 2.0 comes from an examination of industry financial statements. NHTSA examined industry 10-K submissions to the Securities and Exchange Commission from the period 1972-1997.[k] The cost information in these submissions represents all industry operations, including both OEM and supplier-sourced technologies. During this period, the RPE averaged 1.5 while varying slightly, but never dropped below 1.4 or exceeded 1.6. At no time did the average RPE approach the 2.0 value advocated by NADA. The results are shown, together with the 2007 results from Rogozhin et al in the following figure:



Sixth, the comparison of the Vega and the Cruze uses circular logic; it assumes its conclusion. The direct costs of the vehicles are calculated using an RPE of 2, and the NADA analysis then calculates a quality difference based on the change in direct costs. The magnitude of the quality difference is then discovered to correspond to an RPE of 2, although it is also an inevitable result of the initial assumption of an RPE of 2. The analysis provided can be replicated with any value of RPE. This argument thus provides no evidence on the value of the RPE.

For these reasons, we do not accept NADA's request to use an RPE of 2x., and instead continue with our use of ICMs as the basis for our central analysis. However, the agencies recognize that there is uncertainty regarding the impact on indirect costs of regulatorily imposed changes. For this reason, both agencies have conducted sensitivity analyses using different indirect cost estimates. EPA presents its sensitivities in Chapter 3 of its final RIA. For its part, NHTSA rejects the ICCT proposal to eliminate sensitivity analyses examining the RPE and presents the impact of using the RPE as a basis for indirect costs in its analysis in Chapters 7 and 10 of NHTSA's FRIA. In addition, RPEs are incorporated into the Probabilistic Uncertainty analysis in Chapter 12 of NHTSA's FRIA.

[k] Spinney, B.C., Faigin, B.M, Bowie, N.N, Kratzke, S.R., Advanced Air Bag Systems Cost, Weight, and Lead Time Analysis Summary Report, Contract No. DTNH22-96-0-12003, Task Orders – 001, 003, and 005.

3.2.2.3 Stranded capital

Because the production of automotive components is capital-intensive, it is possible for substantial capital investments in manufacturing equipment and facilities to become "stranded" (where their value is lost, or diminished). This would occur when the capital is rendered useless (or less useful) by some factor that forces a major change in vehicle design, plant operations, or manufacturer's product mix, such as a shift in consumer demand for certain vehicle types. It can also be caused by new standards that phase-in at a rate too rapid to accommodate planned replacement or redisposition of existing capital to other activities. The lost value of capital equipment is then amortized in some way over production of the new technology components.

It is difficult to quantify accurately any capital stranding associated with new technology phase-ins under the final standards because of the iterative dynamic involved – that is, the new technology phase-in rate strongly affects the potential for additional cost due to stranded capital, but that additional cost in turn affects the degree and rate of phase-in for the same or other individual competing technologies. In addition, such an analysis is very company-, factory-, and manufacturing process-specific, particularly in regard to finding alternative uses for equipment and facilities. Nevertheless, in order to account for the possibility of stranded capital costs, the agencies asked FEV to perform an analysis, using conservative assumptions, of the potential stranded capital costs associated with rapid phase-in of technologies due to new standards, using data from FEV's primary teardown-based cost analyses.[22] Since the direct manufacturing costs developed by FEV assumed a 10 year production life (*i.e.*, capital costs amortized over 10 years) the agencies applied the FEV derived stranded capital costs whenever technologies were replaced prior to being utilized for the full 10 years. The other option would have been to assume a 5 year product life (*i.e.*, capital costs amortized over 5 years), which would have increased the direct manufacturing costs. It seems only reasonable to account for stranded capital costs in the instances where the fleet modeling performed by the agencies replaced technologies before the capital costs were fully amortized. The agencies did not derive or apply stranded capital costs to all technologies only the ones analyzed by FEV. While there is uncertainty about the possible stranded capital costs (*i.e.*, understated or overstated), their impact would not call into question the overall results of our cost analysis or otherwise affect the stringency of the standards, since costs of stranded capital are a relatively minor component of the total estimated costs of the rules.

The assumptions made in FEV's stranded capital analysis with potential for major impacts on results are:

- All manufacturing equipment was bought brand new when the old technology started production (no carryover of equipment used to make the previous components that the old technology itself replaced).
- 10-year normal production runs: Manufacturing equipment used to make old technology components is straight-line depreciated over a 10-year life.
- Factory managers do not optimize capital equipment phase-outs (that is, they are assumed to routinely repair and replace equipment without regard to whether or not it will soon be scrapped due to adoption of new vehicle technology).

- Estimated stranded capital is amortized over 5 years of annual production at 450,000 units (of the new technology components). This annual production is identical to that assumed in FEV's primary teardown-based cost analyses. The 5-year recovery period is chosen to help ensure a conservative analysis; the actual recovery would of course vary greatly with market conditions.

FEV assembled a team of manufacturing experts to perform the analysis, using a methodology with the following key steps for each vehicle technology scenario:

1) Identify all of the old technology components that are no longer used or that are modified in the new technology vehicles (from the comparison bills of materials developed in the primary teardown-based analyses).

2) For each of these components identify the manufacturing equipment and tooling needed to make it.

3) Estimate the new-purchase $ value of each item identified in step 2.

4) Assign an "Investment Category" to each equipment item identified in step 2, based on an assessment by FEV's experts of recoverable value:

   - Flexible: Equipment can be used to manufacture new technology or other parts (0% stranded)
   - Re-Useable: Equipment can be used in alternative industries, sold at 50% of its remaining value (50% stranded)
   - Semi-Dedicated: Estimate that 50% of equipment is flexible (50% stranded)
   - Dedicated: Custom manufacturing equipment (100% stranded)

5) Assign an "Investment Category" to each tooling item identified in step 2, based on an assessment by FEV's experts of recoverable value:

   - Flexible: Can be used for manufacturing new technology parts (0% stranded)
   - Perishable: Frequent replacement of tooling (0% stranded)
   - Semi-Dedicated Tooling: Estimate that 50% of tooling is dedicated (50% stranded)
   - Dedicated: Commodity-specific (100% stranded)

6) Multiply the % stranding values from steps 4 and 5 by the $ values from step 3.

7) Multiply the results in step 6 by 70%, 50%, and 20% for 3-, 5-, and 8-year stranding scenarios, respectively. That is, an old technology, for which production is truncated prematurely after only 8 years, will experience the stranding of 20% (the last 2 years of its 10-year normal production run) of its associated remaining capital value.

8) Sum the results in step 7 to obtain overall stranded capital costs.

9) Divide the results in step 8 by 2,250,000 (5 years x 450,000 units/year) to obtain $/vehicle values, applicable to new technology vehicles for the 1st 5 years of their production due to the assumed 5-year recovery period.

The stranded capital analysis was performed for three transmission technology scenarios, two engine technology scenarios, and one hybrid technology scenario, as shown in Table 3-3. The methodology used by EPA in applying these results to the technology costs is described in Chapter 3 of EPA's RIA. The methodology used by NHTSA in applying these results to the technology costs is described in NHTSA's RIA section V.

Table 3-3 Stranded Capital Analysis Results (2010 dollars /vehicle)

Replaced technology	New technology	Stranded capital cost per vehicle when replaced technology's production is ended after:		
		3 years	5 years	8 years
6-speed AT	6-speed DCT	$56	$39	$16
6-speed AT	8-speed AT	$48	$34	$14
6-speed DCT	8-speed DCT	$28	$20	$8
Conventional V6	DSTGDI I4	$57	$40	$16
Conventional V8	DSTGDI V6	$61	$43	$17
Conventional V6	Power-split HEV	$112	$80	$32

DSTGDI=Downsized, turbocharged engine with stoichiometric gasoline direct injection.

3.2.3 Cost reduction through manufacturer learning[l]

For this final rule, consistent with the proposal, we have not changed our estimates of learning and how learning will impact costs going forward from what was employed in the analysis for the MYs 2012-2016 light-duty vehicle rule. However, we have updated our terminology in an effort to clarify that we consider there to be one learning effect—learning by doing—which results in cost reductions occurring with every doubling of production.[m] In the past, we have referred to volume-based and time-based learning. Our terms were meant only to denote where on the volume learning curve a certain technology was—"volume-based learning" meant the steep portion of the curve where learning effects are greatest, while "time-based learning" meant the flatter portion of the curve where learning effects are less pronounced. Unfortunately, our terminology led some to believe that we were implementing two completely different types of learning—one based on volume of production and the other based on time in production. Our new terminology—steep portion of the curve and flat portion of curve—is simply meant to make more clear that there is one learning curve and some technologies can be considered to be on the steep portion while others are well into the

[l] Note that our approach to accounting for cost reduction through manufacturer learning is unchanged since the proposal.

[m] Note that this new terminology was described in the recent heavy-duty GHG final rule (see 76 FR 57320). The learning approach used in this analysis is entirely consistent with that used and described for the heavy-duty analysis.

flatter portion of the curve. These two portions of the volume learning curve are shown in Figure 3-1.

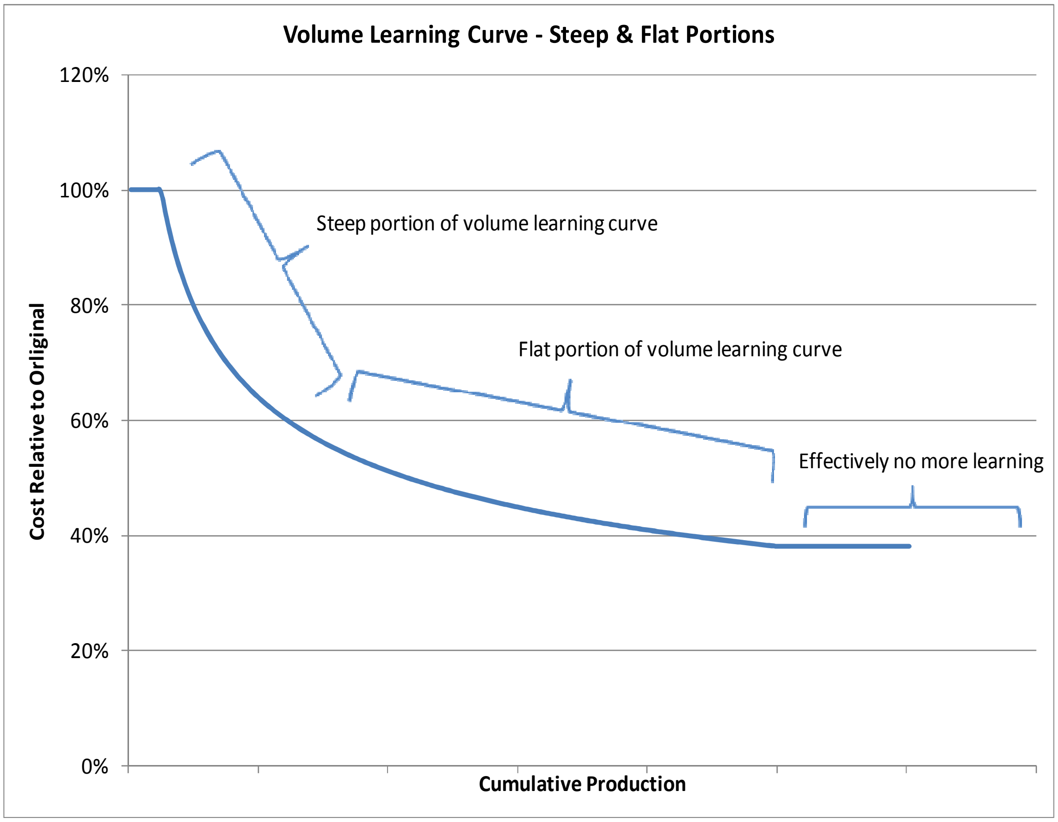


Figure 3-1 Steep & Flat Portions of the Volume Learning Curve

For some of the technologies considered in this analysis, manufacturer learning effects would be expected to play a role in the actual end costs. The "learning curve" or "experience curve" describes the reduction in unit production costs as a function of accumulated production volume. In theory, the cost behavior it describes applies to cumulative production volume measured at the level of an individual manufacturer, although it is often assumed—as both agencies have done in past regulatory analyses—to apply at the industry-wide level, particularly in industries like the light duty vehicle production industry that utilize many common technologies and component supply sources. Both agencies believe there are indeed many factors that cause costs to decrease over time. Research in the costs of manufacturing has consistently shown that, as manufacturers gain experience in production, they are able to apply innovations to simplify machining and assembly operations, use lower cost materials, and reduce the number or complexity of component parts. All of these factors allow manufacturers to lower the per-unit cost of production. We refer to this phenomenon as the manufacturing learning curve.

NHTSA and EPA included a detailed description of the learning effect in the MYs 2012-2016 light-duty rule and the more recent heavy-duty rule.[23] Most studies of the effect of experience or learning on production costs appear to assume that cost reductions begin only after some initial volume threshold has been reached, but not all of these studies specify this threshold volume. The rate at which costs decline beyond the initial threshold is usually expressed as the percent reduction in average unit cost that results from each successive doubling of cumulative production volume, sometimes referred to as the learning rate. Many estimates of experience curves do not specify a cumulative production volume beyond which cost reductions would no longer occur, instead depending on the asymptotic behavior of the effect for learning rates below 100 percent to establish a floor on costs.

In past rulemaking analyses, as noted above, both agencies have used a learning curve algorithm that applied a learning factor of 20 percent for each doubling of production volume. NHTSA has used this approach in analyses supporting recent CAFE rules. In its analyses, EPA has simplified the approach by using an "every two years" based learning progression rather than a pure production volume progression (i.e., after two years of production it was assumed that production volumes would have doubled and, therefore, costs would be reduced by 20 percent).[n]

In the MYs 2012-2016 light-duty rule and the heavy-duty GHG final rule, the agencies employed an additional learning algorithm to reflect the volume-based learning cost reductions that occur further along on the learning curve. This additional learning algorithm was termed "time-based" learning in the MYs 2012-2016 rule simply as a means of distinguishing this algorithm from the volume-based algorithm mentioned above, although both of the algorithms reflect the volume-based learning curve supported in the literature. As described above, we are now referring to this learning algorithm as the "flat portion" of the learning curve. This way, we maintain the clarity that all learning is, in fact, volume-based learning, and that the level of cost reductions depend only on where on the learning curve a technology's learning progression is. We distinguish the flat portion of the curve from the steep portion of the curve to indicate the level of learning taking place in the years following implementation of the technology (see Figure 3-1). The agencies have applied learning effects on the steep portion of the learning curve for those technologies considered to be newer technologies likely to experience rapid cost reductions through manufacturer learning, and learning effects on the flat portion learning curve for those technologies considered to be more mature technologies likely to experience only minor cost reductions through manufacturer learning. As noted above, the steep portion learning algorithm results in 20

[n] To clarify, EPA has simplified the steep portion of the volume learning curve by assuming that production volumes of a given technology will have doubled within two-years time. This has been done largely to allow for a presentation of estimated costs during the years of implementation, without the need to conduct a feedback loop that ensures that production volumes have indeed doubled. If we were to attempt such a feedback loop, we would need to estimate first year costs, feed those into OMEGA, review the resultant technology penetration rate and volume increase, calculate the learned costs, feed those into OMEGA (since lower costs would result in higher penetration rates, review the resultant technology penetration rate and volume increase, etc., until an equilibrium was reached. To do this for all of the technologies considered in our analysis is simply not feasible. Instead, we have estimated the effects of learning on costs, fed those costs into OMEGA, and reviewed the resultant penetration rates. The assumption that volumes have doubled after two years is based solely on the assumption that year two sales are of equal or greater number than year one sales and, therefore, have resulted in a doubling of production. This could be done on a daily basis, a monthly basis, or, as we have done, a yearly basis.

percent lower costs after two full years of implementation (*i.e.*, the MY 2016 costs would be 20 percent lower than the MYs 2014 and 2015 costs). Once two steep portion learning steps have occurred, flat portion learning at 3 percent per year becomes effective for 5 years. Beyond 5 years of learning at 3 percent per year, 5 years of learning at 2 percent per year, then 5 at 1 percent per year become effective.

Learning effects are applied to most but not all technologies because some of the expected technologies are already used rather widely in the industry and we therefore assume that learning impacts have already occurred. The steep portion learning algorithm was applied for only a handful of technologies that are considered to be new or emerging technologies. Most technologies have been considered to be more established given their current use in the fleet and, hence, the lower flat portion learning algorithm has been applied. The learning algorithms applied to each technology and the applicable timeframes are summarized in Table 3-4.

Table 3-4 Learning Effect Algorithms Applied to Technologies Used in this Analysis

Technology	Steep learning	Flat learning	No learning
Engine modifications to accommodate low friction lubes			2012-2025
Engine friction reduction – level 1 & 2			2012-2025
Lower rolling resistance tires – level 1			2012-2025
Low drag brakes			2012-2025
Secondary axle disconnect		2012-2025	
Electric/Plug-in vehicle battery charger installation labor			2012-2025
Variable valve timing		2012-2025	
Variable valve lift		2012-2025	
Cylinder deactivation		2012-2025	
Stoichiometric gasoline direct injection		2012-2025	
Aggressive shift logic – level 1 & 2		2012-2025	
Early torque converter lockup		2012-2025	
5/6/7/8 speed auto transmission		2012-2025	
6/8 speed dual clutch transmission		2012-2025	
High efficiency gearbox		2012-2025	
Improved accessories – level 1 & 2		2012-2025	
Electronic/electro-hydraulic power steering		2012-2025	
Aero improvements – level 1 & 2		2012-2025	
Conversion to DOHC without reducing # of cylinders		2012-2025	
Air conditioner related hardware		2012-20205	
Air conditioner alternative refrigerant	2016-2020	2021-2025	
Cooled EGR		2012-2025	
Conversion to Atkinson cycle		2012-2025	
Turbocharging & downsizing		2012-2025	
Mass reduction		2012-2025	

Advanced diesel		2012-2025	
Hybrid/Electric/Plug-in vehicle non-battery components		2012-2025	
P2 Hybrid vehicle battery-pack components	2012-2016	2017-2025	
Electric/Plug-in vehicle battery-pack components	2012-2025[a]		
Electric/Plug-in vehicle battery charger components	2012-2025[a]		
Stop-start	2012-2015	2016-2025	
Lower rolling resistance tires – level 2	2017-2021	2022-2025	

[a] Note that the steep learning effects have for EV and PHEV battery packs and charger components have been carried through 5 learning cycles but at a decelerated pace as described in the text.

The learning effects discussed here impact the technology costs in that those technology costs for which learning effects are considered applicable are changing throughout the period of implementation and the period following implementation. For example, some of the technology costs considered in this analysis are taken from the MYs 2012-2016 light-duty rule. Many of the costs in the MYs 2012-2016 light-duty rule were considered "applicable" for the 2012 model year. If flat-portion learning were applied to those technologies, the 2013 cost would be 3 percent lower than the 2012 cost, and the 2014 model year cost 3 percent lower than the 2013 cost, etc. As a result, the MYs 2017-2025 costs for a given technology used in this analysis reflect those years of flat learning and would not be identical to the 2012 model year cost for that same technology presented in the MYs 2012-2016 light-duty rule.

Because of the nature of battery pack development (i.e., we are arguably still in the research phase for the types of batteries considered in this final rule, and cost reduction through manufacturer-based learning has only just begun), the agencies have carried the learning curve through five steep learning steps although at a somewhat slower pace than every two years. This has been done in an effort to maintain the shape of a traditional learning curve. This curve was developed by using the ANL BatPaC model costs as direct manufacturing costs applicable in the 2025 MY. We have then unlearned those costs back to 2012 using the curve shown in Figure 3-2. This is the same curve used in the 2010 TAR (see 2010 TAR at page B-22). This allows the agencies to estimate costs in MYs 2017 through 2025, as well as those costs in each year back to MY 2012, if desired. As noted, this learning curve consists of 5 full learning steps on the steep portion of the learning curve, each of which results in costs being reduced 20 percent relative to the prior step. These learning steps are shown occurring every two years beginning in 2012 until 2020, at which time a 5 year gap is imposed until 2025 when the fifth steep learning step occurs. Beyond 2025, learning on the flat portion of the curve begins at 3 percent per year cost reductions. The smooth line shows a logarithmic curve fit applied to the learning curve as the agencies' cost model would apply learning.

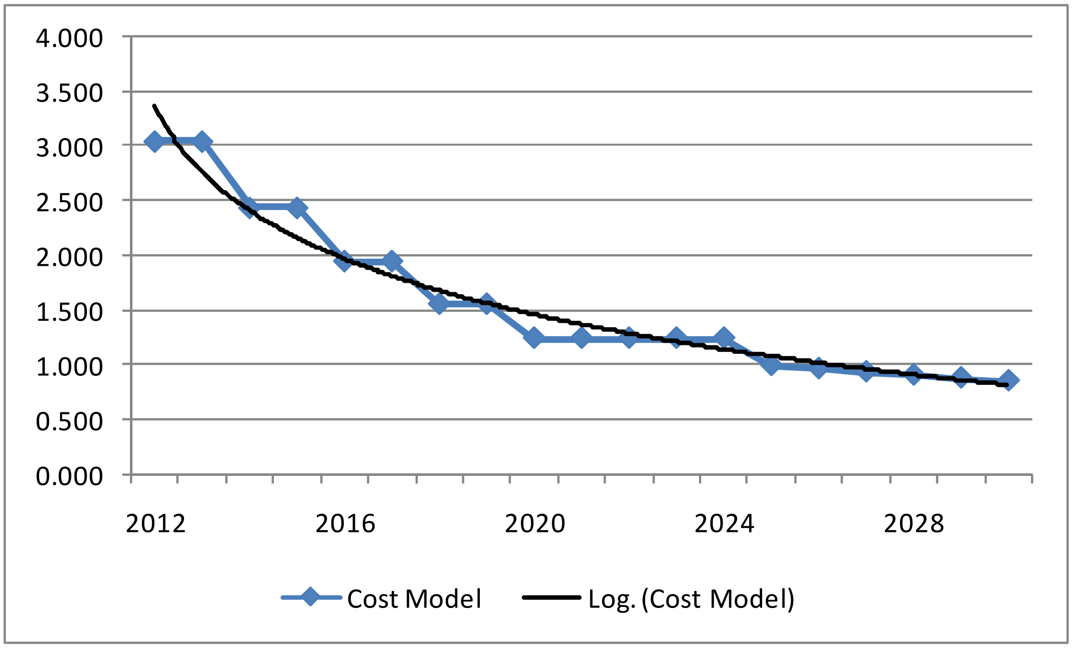


Figure 3-2 Learning Curve used for EV & PHEV Battery-Packs and In-Home Charger Costs

Note that the effects of learning on individual technology costs can be seen in the cost tables presented in section 3.3, below. For each technology, we show direct manufacturing costs for the years 2017 through 2025. The changes shown in the direct manufacturing costs from year-to-year reflect the cost changes due to learning effects.

3.2.4 Costs Updated to 2010 Dollars[o]

This change is simply to update any costs presented in earlier analyses to 2010 dollars using the GDP price deflator as reported by the Bureau of Economic Analysis on February 9, 2012. The factors used to update costs from 2007, 2008 and 2009 dollars to 2010 dollars are shown below.

	2007	2008	2009	2010
Price Index for Gross Domestic Product	106.2	108.6	109.7	111.0
Factor applied to convert to 2010 dollars	1.04	1.02	1.01	1.00

Source: Bureau of Economic Analysis, Table 1.1.4. Price Indexes for Gross Domestic Product, downloaded 2/9/2012, last revised 1/27/2012.

[o] Note that costs in the proposal were in terms of 2009 dollars.

3.3 How did the agencies determine effectiveness of each of these technologies?

The agencies determined the effectiveness of each individual technology with a process similar to the one used for the 2012-2016 light duty vehicle GHG and CAFE standards. The individual effectiveness of several technologies discussed in this rule that were present in the earlier rule were left largely unchanged while others were updated. EPA and NHTSA reviewed recent confidential manufacturer estimates of technology effectiveness and found them to be generally consistent with our estimates. Additionally, EPA used vehicle simulation modeling to gain further insight on existing and new technologies for this rulemaking. EPA conducted a vehicle simulation project (described in 3.3.1) that included a majority of the technologies, the results of which:

- informed existing individual technology effectiveness values,
- provided data for newly introduced technologies, and
- most importantly, provided an interactive data source with which to update and calibrate the new LP model

The lumped parameter model then served as the primary tool in evaluating the individual technology effectiveness estimates the combined effectiveness of groups of technologies (or packages) and synergy factors, as described in 3.3.2. The effectiveness values, in conjunction with costs, were then applied to vehicles across the fleet for use in the Agencies' respective compliance models. For the final rule, NHTSA conducted a vehicle simulation project with Argonne National Laboratory (ANL), as described in NHTSA's FRIA that performed additional analyses on mild hybrid technologies and advanced transmissions to help NHTSA develop effectiveness values better tailored for the CAFE model's incremental structure. The effectiveness values that were developed by ANL for the mild hybrid vehicles were applied by both agencies for the final rule. Additionally, NHTSA updated the effectiveness values of advanced transmissions coupled with naturally-aspirated engines based on ANL's simulation work for the final rule.

3.3.1 Vehicle simulation modeling

3.3.1.1 Background

For regulatory purposes, the fuel economy of any given vehicle is determined by placing the vehicle on a chassis dynamometer (akin to a large treadmill that puts the vehicle's wheels in contact with one or more rollers, rather than with a belt stretched between rollers) in a controlled environment, driving the vehicle over a specific driving cycle (in which driving speed is specified for each second of operation), measuring the amount of carbon dioxide emitted from the vehicle's tailpipe, and calculating fuel consumption based on the density and carbon content of the fuel.

One means of determining the effectiveness of a given technology as applied to a given vehicle model would be to measure the vehicle's fuel economy on a chassis dynamometer, install the new technology, and then re-measure the vehicle's fuel economy. However, most technologies cannot simply be "swapped out," and even for those that can, simply doing so without additional engineering work may change other vehicle characteristics (*e.g.*, ride, handling, performance, etc.), producing an "apples to oranges" comparison.

Some technologies can also be more narrowly characterized through bench or engine dynamometer (*i.e.*, in which the engine drives a generator that is, in turn, used to apply a controlled load to the engine) testing. For example, engine dynamometer testing could be used to evaluate the brake-specific fuel consumption (*e.g.*, grams per kilowatt-hour) of a given engine before and after replacing the engine oil with a less viscous oil. However, such testing does not provide a direct measure of overall vehicle fuel economy or changes in overall vehicle fuel economy.

For a vehicle that does not yet exist, as in the agencies' analyses of CAFE and GHG standards applicable to future model years, even physical testing can provide only an estimate of the vehicle's eventual fuel economy. Among the alternatives to physical testing, automotive engineers involved in vehicle design make use of computer-based analysis tools, including a powerful class of tools commonly referred to as "full vehicle simulation." Given highly detailed inputs regarding vehicle engineering characteristics, full vehicle simulation provides a means of estimating vehicle fuel consumption over a given drive cycle, based on the explicit representation of the physical laws governing vehicle propulsion and dynamics. Some vehicle simulation tools also incorporate combustion simulation tools that represent the combustion cycle in terms of governing physical and chemical processes. Although these tools are computationally intensive and required a great deal of input data, they provide engineers involved in vehicle development and design with an alternative that can be considerably faster and less expensive than physical experimentation and testing.

Properly executed, methods such as physical testing and full vehicle simulation can provide reasonably (though not absolutely) certain estimates of the vehicle fuel economy of specific vehicles to be produced in the future. However, when analyzing potential CAFE and GHG standards, the agencies are not actually designing specific vehicles. In this rulemaking analysis, the agencies have considered the implications of new standards that will apply to the average performance of manufacturers' entire production lines. For this type of analysis, precision in the estimation of the fuel economy of individual vehicle models is not essential; although it is important that the agency avoid systematic upward or downward bias, uncertainty at the level of individual models is mitigated by the fact that compliance with CAFE and GHG standards is based on average fleet performance.

DOT's CAFE model and EPA's OMEGA are not full vehicle simulation models. Both models use higher-level estimates of the efficacy of different technologies or technology packages. Both models apply methods to avoid potential double-counting of efficacy addressing specific energy loss mechanisms (*e.g.*, pumping losses), and for this FRM, consistent with the proposal, both agencies applied estimates using EPA's lumped parameter model, which was updated using results of full vehicle simulation performed by Ricardo, PLC. Although full vehicle simulation could, in principle, be fully integrated into the agencies' model-by-model analyses of the entire fleet to be projected to be produced in future model years, this level of integration would be infeasible considering the size and complexity of the fleet. Also, considering the forward-looking nature of the agencies' analyses, and the amount of information required to perform full vehicle simulation, this level of integration would involve misleadingly precise estimates of fuel consumption and CO_2 emissions. Still, while the agencies have used results of full vehicle simulation to inform the development of model inputs for performing fleet-level analysis, information from other sources (*e.g.*, vehicle testing) could be considered when developing such model inputs.

3.3.1.2 2011 Ricardo Simulation Study

For this rule EPA built upon its 2008 vehicle simulation project[24] used to support the 2012-2016 light duty vehicle GHG and CAFE standards. As in the initial project, the technical work was conducted by the global engineering consulting firm, Ricardo, Inc. (under subcontract to SRA Corporation), using its MSC.EASY5 dynamic vehicle simulation model. This section is intended to supplement the main report which has been recently published and peer-reviewed[1]. While this project represents a new round of full-scale vehicle simulation of advanced technologies, the scope has also been expanded in several ways to broaden the range of vehicle classes and technologies considered, consistent with a longer-term outlook through model years 2017-2025. The expanded scope also includes a new analytical tool (complex systems analysis tool) to assist in interpolating the response surface modeling (RSM) data and visualizing technology effectiveness. This tool was especially useful in isolating effectiveness trends during development of the updated Lumped Parameter model.

The agencies try to use publicly available information as the basis for technical assessments whenever possible. Because these standards extend to MY 2025, and include some technologies that are not currently in production and for which there is limited information available in the literature, some of the technology inputs used to estimate effectiveness are based on confidential business information. This includes the inputs related to the technologies listed below which were based on confidential business information belonging to Ricardo, Inc, and their expert judgment that contributed to projecting how these technologies might improve in the future. The agencies have also considered information which is in the public domain, in particular for turbo-charged, downsized GDI engines as discussed in Section 3.4.1.8, as well as confidential information on engine and transmission technologies from automotive suppliers which directionally was in line with the information considered by Ricardo. In the draft TSD, the agencies encouraged commenters to submit technical information, preferably that may be released publicly, related to these technologies, particularly on their effectiveness and ability to be implemented in a way that maintains utility. The agencies sought comment and data on the following technologies individually or in combination: advanced turbocharged and downsized, atkinson, and advanced diesel (*e.g.* projected BSFC maps) engines, hybrid powertrain control strategies, optimized transmission shift control strategies, and transmission efficiency improvement. Few comments were received specific to these technologies, although the Alliance emphasized that the agencies should examine the progress in the development of powertrain improvements as part of the mid-term evaluation and determine if researchers are making the kind of breakthroughs anticipated by the agencies for technologies like high-efficiency transmissions. Additionally, Volkswagen commented that while high BMEP (27-31) bar engines with cooled EGR are currently the subject of research, Volkswagen believed that there are significant obstacles, such as thermal and mechanical loads and their impacts on costs and durability, low-end torque performance and part-load efficiency, which need to be overcome before these engines represent a viable option for improving fuel economy while maintaining customer satisfaction. The agencies recognize Volkswagen's comments, but note that the analysis for this final rule considered only high BMEP engines up to 27 bar, and will be monitoring the progress of this technology carefully and consider it at the mid-term evaluation. Moreover, since this technology does not reach significant levels in our modeling analyses of the final standards until after MY 2021, the agencies will evaluate industry experience with this technology at the mid-term evaluation and can adjust assumptions as appropriate.

Below is a summary of the significant content changes from the 2008 simulation project to the 2011 simulation project that supports the final rule, consistent with the proposal.

3.3.1.2.1 More Vehicle Classes

Two additional vehicle classes were considered, for a total of seven classes: a small car (subcompact) and a medium/heavy duty truck class. The inclusion of the small car class increased the fidelity of the results by capturing engineering differences unique to the smallest vehicles in the market. The inclusion of the medium/heavy duty truck was meant primarily to support EPA's analysis for the Heavy Duty GHG Rule[25]. It is worth noting that these vehicle classes are for simulation purposes only and are not be confused with regulatory classes, OMEGA classes, or NHTSA's technology subclasses for CAFE modeling.

3.3.1.2.2 More engine and vehicle technologies

The original 2008 project modeled several engine and transmission technologies that were expected to become commercially available within the 2012-2016 time frame. These technologies included advanced valvetrain technologies (such as variable valve timing and lift, cylinder deactivation), turbocharged and downsized engines, as well as 6 speed automatic transmissions, CVTs[p] and dual-clutch transmissions. The current project built on top of this effort with the inclusion of several new engine and vehicle technologies. Highlighted examples included:

- Advanced, highly downsized, high BMEP[q] turbocharged engines
- High efficiency transmissions with 8 speeds and optimized shift strategies to maximize vehicle system efficiency
- Atkinson-cycle engines for hybrids
- Stop-start (or idle-off) technology

A discussion of these technologies is included Section 3.3.1.2, and also in the 2011 vehicle simulation report[1].

[p] Continuously variable transmissions
[q] BMEP refers to brake mean effective pressure, a common engineering metric which describes the specific torque of an engine, as a way of comparing engines of different sizes. It is usually expressed in units of bar, or kPa, Current naturally aspirated production engines typically average 10-12 bar BMEP, while modern turbocharged engines are now exceeding 20 bar BMEP with regularity. Simply put, a 20 bar BMEP turbocharged engine will provide twice the torque of an equivalently-sized engine that achieves 10 bar BMEP.

3.3.1.2.3 Includes hybrid architectures

For the first time, this new work includes modeling of hybrid architectures for all vehicle classes. Two main classes of hybrids were considered:

- Input powersplit hybrids. Examples of input powersplits in the market today include the Ford Fusion HEV and the Toyota Prius.
- P2 hybrids. An example of the P2 hybrid is the Hyundai Sonata Hybrid.

While input powersplit hybrids remain a very likely hybrid architecture choice for some manufacturers, the agencies focused solely on P2 hybrids compared to powersplit hybrids due to their apparent cost-effectiveness advantage in future years.

Ricardo proprietary methodology was used to develop control strategies for each architecture, the details of which can be found in section 6.8 of the 2011 project report[1].

3.3.1.2.4 Complex systems tool for data analysis

In the original 2008 project, EPA staff selected unique technology packages, based on engineering judgment, to cover a representative subset of possible vehicle options ending in MY 2016. The expanded project time horizon (through MY 2025) and increased complexity of potential vehicle technology interactions (including hybrids) made package selection much more difficult. To account for unforeseen results and trends which might exist, EPA and Ricardo adopted a complex systems approach, which is a rigorous computational strategy designed to mathematically account for multiple input variables and determine the significance of each (the complex systems approach is described in further detail in the 2011 Ricardo report). As a comparison, in the 2008 study, twenty-six unique technology packages spanning five vehicle classes were selected by EPA staff and then modeled. For this project a set of core technology packages were chosen for each vehicle class, constituting a total of 107 unique vehicle packages ("nominal runs"), which are shown as Table 3-5 and Table 3-6 in 3.3.1.2.8. A neural network Complex Systems approach to design of experiments (DOE) was then applied to generate a set of response surface models (RSM), in which several input parameters were varied independently over a specified range to identify the complex relationship between these inputs and the vehicle performance. Using these methods, the vehicle simulation was run for a set of discrete input variables chosen based on a full factorial analysis, using a computationally efficient algorithm to select each input variable within the design space, allowing for subsequent statistical regression of the output variables. This approach resulted in an average of approximately two thousand independent simulation runs for each of the 100+ vehicle packages, the outputs of which were interpolated in the data analysis tool developed for this modeling activity. For each of these nominal and DOE runs Ricardo provided detailed 10-hz output data csv files for review[r].

[r] Stakeholders wishing to obtain this data may contact EPA to arrange for transfer of the data. Due to the considerable size of the files (2 terabytes), stakeholders must supply their own storage media.

An interactive Complex Systems analysis and visualization tool was developed to interpret the vast arrays of RSM data generated as part of the project. It was created to sample a selected portion of the design space populated using the DOE approach described above, and then interpret the RSM data set in a form that could be used to calibrate the lumped parameter model (reference the equivalent-performance results in Section 3.3.1.2.18). For more detail on the use of the RSM tool, refer to the 2011 Ricardo report[1].

3.3.1.2.5 Process

The core technical work, completed in February 2011, consisted of the following steps:

- Definition of project scope
- Selection of vehicle classes and baseline vehicle characteristics
- Selection of vehicle architectures and individual technologies
- Selection of swept variables for use in the RSM matrix
- Selection of vehicle performance metrics
- Review and revision of the input assumptions and modeling process
- Build and run the baseline EASY5 vehicle models
- Review of baseline runs and checking for errors
- Build and run the nominal technology package EASY5 vehicle models
- Review results and debug
- Run complete DOE matrix for each technology package
- Incorporation of DOE results into RSM tool

3.3.1.2.6 Definition of project scope

At project initiation, an advisory committee was formed and led by EPA to help guide the analysis. The advisory committee consisted of technical experts from CARB and The ICCT, the latter of which co-founded the project. A complete list of advisory committee members is found in the vehicle simulation project report[1]. The committee agreed upon the underlying ground rules, reviewed modeling assumptions and identified the desired vehicle architectures and selected technologies for review. The boundaries for the project are highlighted (quoted) below:

- A total of seven vehicle classes will be included: small car, standard car, large car, small and large MPVs (multi-purpose vehicles), truck and HD truck

- LDV technologies must have the potential to be commercially deployed in the MYs 2020-2025 timeframe

- Vehicle sizes (footprint and interior space) for each class will be largely unchanged from MY 2010 to MYs 2020-2025

- Hybrid vehicles will use an advanced hybrid control strategy, focusing on battery state-of-charge management, but will not compromise vehicle drivability

- Ricardo simulation study uses certification gasoline and 40 cetane pump diesel to determine the effectiveness of engine technologies. The certification gasoline typically has an RON of approximately 95 versus approximately 91 for regular grade 87 anti-knocking index gasoline.

- It is assumed that MYs 2020-2025 vehicles will meet future California LEV III requirements for criteria pollutants, approximately equivalent to current SULEV II (or EPA Tier 2 Bin 2) emissions levels

- Changes in vehicle road loads including mass, aerodynamic drag, and rolling resistance, will not be accounted for in any of the modeled technologies. Instead, changes in vehicle road loads may be addressed through user-specified continuous input variables in the Complex Systems tool.

The committee also decided that the following technologies fell outside the scope of the project, either due to project resource limitations, lack of sufficient input data, or a low potential to be commercially deployed in the timeframe considered:

- Charge-depleting powertrains (e.g. plug-in hybrids and electric range-extended vehicles) and electric vehicles

- Fuel cell-powered vehicles

- Non-reciprocating internal combustion engines or external combustion engines

- Manual transmissions and single-clutch automated manual transmissions (AMTs)

- Kinetic energy recovery systems other than battery systems

- Intelligent vehicle-to-vehicle (V2V) and vehicle-to-infrastructure optimization technology

- Bottoming cycles (such as organic Rankine cycles) for energy recovery

- Vehicle safety systems or structures will not be explicitly modeled for vehicles, as it is beyond the scope of the study

The committee also selected a set of swept input variables (vehicle parameters) which were considered most important to vehicle fuel economy and performance (swept variables are continuously variable input values that affect vehicle output efficiency in a smooth function for the response surface model). These variables consisted of engine displacement, final drive ratio, electric drive motor size (for hybrids), as well as road load factors (vehicle mass, aerodynamic drag, and rolling resistance). All of these input variables were randomized in each vehicle design of experiment matrix and then incorporated into the post-processing RSM data visualization tool.

3.3.1.2.7 Selection of vehicle classes and baseline vehicle characteristics

In order to estimate both technology costs and CO2 reduction estimates, it is necessary to describe the baseline vehicle characteristics as the basis from which comparisons may be drawn. In the MYs 2012-2016 light-duty vehicle rule the vehicle baseline was defined as having a naturally aspirated gasoline engine with a port-fuel injection system, two intake and two exhaust valves and fixed valve timing and lift; the baseline transmission was a conventional 4-speed automatic, with no hybrid systems. These vehicles are referred to throughout this section as the "2008 baselines." For the present study, EPA and Ricardo elected to include a set of "2010 baseline" technology vehicles, which reflect MY 2010 trends in engine and vehicle technology as well as some technologies that are expected to be widespread within a few years. It is important to note that the 2010 baseline vehicles in the Ricardo study do not reflect the technology content of the baseline fleet vehicles used by each agency in their respective compliance modeling. The Ricardo 2010 baseline vehicles are only used in the analysis required to establish effectiveness and synergies in the lumped parameter model. The 2010 baseline vehicles all include an engine with dual overhead camshaft and dual-independent intake/exhaust valve timing, a six-speed automatic transmission, 12-volt idle off (stop-start) functionality and an alternator with partial energy regeneration capability. There is no change in the engine displacement or vehicle road load coefficients between the 2008 baseline and the 2010 baseline vehicles. For a table showing the 2010 baseline vehicle characteristics refer to Appendix 3 of the 2011 Ricardo report[1].

In the Ricardo study, seven vehicle classes were selected for the analysis, in order to more fully represent the broad groupings of a wide variety of products offered in the US passenger car and light-duty truck market. The seven vehicle categories chosen were as follows:

- Small car: a subcompact car typically powered by a small 4 cylinder engine.
- Standard car: a midsize car typically powered by a small 6 cylinder engine.
- Large car: a large passenger car typically powered by a large 6 cylinder engine.
- Small MPV: a small multi-purpose vehicle (MPV) or "crossover" vehicle typically powered by a 4 cylinder engine
- Large MPV: a minivan or large MPV or "crossover" unibody constructed vehicle with a large frontal area, typically powered by a 6 cylinder engine, capable of carrying ~ 6 or more passengers.
- Large truck (1/2 ton): large sports-utility vehicles and large pickup trucks, typically a ladder-on-frame construction, and typically powered by an 8 cylinder engine.
- Class 2b/3 truck (3/4 ton): a large pickup truck (although with a GVW no greater than 8.500 pounds) with a heavier frame intended to provide additional utility (a.k.a. "work" truck), typically powered by a larger 8 cylinder gasoline or diesel engine.

3.3.1.2.8 Technology selection

Ricardo presented the committee with an array of potential technologies that might become commercially viable and present in the light-duty market by MY 2025. EPA and the Advisory Committee suggested additional other technologies, *e.g.* Atkinson engines for hybrids, fast engine warm-up strategies, etc, to consider in the selection process. The complete set of potential technologies can be found in Appendix 2 of the 2011 Ricardo report[1]. After further deliberation within the committee and by Ricardo, a subset of technologies considered most promising (from a technical feasibility and cost effectiveness standpoint) was selected by the committee and Ricardo for inclusion in the project test matrix. The technologies were distributed among four distinct vehicle architectures. These architectures represented unique EASY5 model structures, and are listed below:

- 2010 Baseline vehicles: intended to represent physical replicas of existing vehicle models, although some minor additional content was included (as described in Section 3.3.1.2.7)

- Conventional stop-start: vehicles for the MYs 2020-2025 timeframe that included advanced engines but did not incorporate an electric drive or braking energy recovery. These vehicles all contained a 12 volt stop-start (or idle-off) capability, along with the following technologies further detailed in the 2011 Ricardo simulation study[s]:

    - higher efficiency gearbox (2020 timeframe)
    - optimized shift strategy (best BSFC)
    - alternator regeneration (during braking)
    - high-efficiency alternator
    - advanced engine warmup technologies
    - engine friction reduction (+3.5% fuel consumption reduction over 2008 baseline)

- P2 hybrid: represent a class of hybrids in which the electric drive motor is coupled via a clutch directly to the transmission input shaft. An existing vehicle in the market which most closely represents this architecture is the 2011 Hyundai Sonata Hybrid except that Ricardo recommended a P2 hybrid with a more efficient and cost effective dual clutch transmission in lieu of an automatic transmission. Additional examples of a P2 hybrid approach are the 2011 Volkswagen Touareg Hybrid, the 2011 Porsche S Hybrid, and the 2012 Infiniti M35 Hybrid. Each of these are examples of "first generation" P2 systems, as compared to for example the powersplit hybrid systems offered by Ford, Toyota and or the IMA systems

[s] The technologies included in all of the conventional stop-start packages were expected to be widespread by years 2017-2025. Some "anytime technologies" such as aerodynamic drag and rolling resistance reduction were excluded from the nominal runs, but were incorporated in the complex systems portion of this project.

from Honda which are in their second, third or even fourth generation. The agencies are aware of some articles in trade journals, newspapers and other reviews that some first generation P2 hybrid vehicles with automatic transmissions have trade-offs in NVH and drivability – though these reviews do not cover all of the P2 systems available today, and a number of reviews are very positive with respect to NVH and drivability. For this analysis we are projecting that these issues with some first generation P2 systems can be addressed with no hardware cost increase or reduction in efficiency for future generations of P2 systems developed for the 2017-2025 time frame. The agencies sought comment on our assumptions in this regard, and we requested comment on the applicability of DCTs to P2 hybrid applications, including any challenges associated with NVH or drivability. There were no comments submitted. Key technology assumptions included:

- Lithium-ion battery
- DCT transmission
- Electric drive motor which provides, when combined with a less powerful engine, equivalent 0-60 performance to the baseline vehicle.
- Engine displacement for the P2 hybrids were assumed to be 20% less than their conventional stop-start equivalents

- Input powersplit hybrid: represent a class of hybrids with both an electric drive motor and a separate generator linked to a planetary gearset which effectively controls the overall gear ratio and distribution of tractive and electrical power. Example vehicles in the market include the Toyota Prius and the Ford Fusion hybrid. Key technology assumptions are consistent with those for the P2 hybrid, with the exception of the power split device, which functions as a CVT-type transmission (as is the case in real world examples), and replaces the DCT transmission in the P2 design. As stated previously while this technology was simulated it was not used in this FRM analysis, consistent with the proposal.

Some architectures that seemed less appropriate for certain vehicle classes were omitted. For example, in the Ricardo modeling of the medium/heavy duty truck (a Class 3 vehicle with a GVWR >10,000 pounds, and thus not subject to the final standards in this rulemaking), no P2 or input powersplit hybrids were included. Other technologies that did not seem reasonable for some vehicle classes (such as dry-clutch DCTs for Large MPVs and Trucks) were also excluded in the Ricardo simulations.

In summary, 4 distinct vehicle architectures (including the baselines as an "architecture"), across 7 vehicle classes, and a number of engine and transmission combinations, represented the complete set of vehicle combinations. The test matrices[t] can be

[t] For each vehicle class, each advanced engine option is combined with each advanced transmission. Baseline runs are not combined with other transmissions.

found below in Table 3-5 (for 2010 baselines and conventional stop-start vehicles) and Table 3-6 (for hybrids).

Table 3-5: Nominal Package Matrix for Non-Hybrids

			Advanced Engine				Advanced Transmission				
Vehicle Class	Baseline Engine & 2010 6-Speed Automatic	2010 Diesel & 2010 6-Speed Automatic Transmission	Stoich DI Turbo with CPS	Lean DI Turbo with CPS	EGR DI Turbo with DVA	2020 Diesel	6-Speed Automatic	6-Speed Dry DCT	8-Speed Automatic	8-Speed Dry DCT	8-Speed Wet DCT
Small Car	X		X	X	X	X	X	X			
Standard Car	X		X	X	X				X	X	
Small MPV	X		X	X	X				X	X	
Full Size Car	X		X	X	X	X			X	X	
Large MPV	X		X	X	X	X			X		X
LDT	X		X	X	X	X			X		X
LHDT	X	X	X	X	X	X			X		X

Table 3-6: Nominal package matrix for P2 and Input Powersplit hybrids

	Hybrid Architecture		Advanced Engine				
Vehicle Class	P2 Hybrid with 2020 DCT	Input Powersplit	Stoich DI Turbo with CPS	Lean DI Turbo with CPS	EGR DI Turbo with CPS	Atkinson with CPS	Atkinson with DVA
Small Car	X	X	X	X	X	X	X
Standard Car	X	X	X	X	X	X	X
Small MPV	X	X	X	X	X	X	X
Full Size Car	X	X	X	X	X	X	X
Large MPV	X	X	X	X	X	X	X
LDT	X		X	X	X	X	X
LHDT							

3.3.1.2.9 Selection of the swept input variables and their ranges

The advisory committee agreed upon a set of continuous input variables to be swept in each vehicle package response surface. These variables consisted of both powertrain characteristics (engine displacement, final drive ratio, and electric machine size for hybrids) and road load parameters (rolling resistance coefficient, aerodynamic drag force, and vehicle mass). They were included in the DOE matrix for each vehicle architecture and powertrain configuration, and also serve as inputs to the complex systems visualization tool. Table 3-7 and Table 3-8 show the swept variables used (and their ranges) for the conventional stop-start and hybrid packages, respectively. The ranges represent a percentage of the default value used in the nominal runs.

Table 3-7: Continuous input parameter sweep ranges for conventional stop-start vehicle

Parameter	DoE Range (%)	
Engine Displacement	50	125
Final Drive Ratio	75	125
Rolling Resistance	70	100
Aerodynamic Drag	70	100
Mass	60	120

Table 3-8: Continuous input parameter sweep ranges for P2 and Powersplit hybrid vehicles

	DoE Range (%)			
Parameter	P2 Hybrid		Powersplit	
Engine Displacement	50	150	50	125
Final Drive Ratio	75	125	75	125
Rolling Resistance	70	100	70	100
Aerodynamic Drag	70	100	70	100
Mass	60	120	60	120
Electric Machine Size	50	300	50	150

The ranges were intended to include both the (unknown) optimal value for each technology case, but also wide enough to capture the range of values as they depart from the optimal value (in engineering parlance this is often referred to as finding the "knee" in the curve).

From these variables, a user can determine the sensitivity of each input variable to the vehicle fuel economy and performance. For example, the effect of engine displacement on fuel economy was evaluated for several packages. A more elaborate discussion of engine displacement effects is provided in Section 3.3.1.2.24.2.

3.3.1.2.10 Selection of vehicle performance metrics

For both effectiveness and cost estimates in these rulemakings, the agencies are assuming that vehicles will maintain utility (performance) comparable to the models in the baseline fleet[u]. It was therefore important to maintain equivalent performance in the vehicle simulation modeling of future vehicle technology. The resulting effectiveness estimates were in the context of equivalent performance, which carried over into the lumped parameter model and into the OMEGA and CAFE model packages.

Consistent with the 2008 simulation project, a set of vehicle (acceleration) performance metrics were selected by the advisory committee as a way of measuring "equivalent" vehicle performance. When quantifying vehicle efficiency, it is important that certain other vehicle performance metrics are maintained, such that there are no other competing factors contributing or detracting from the vehicle efficiency. Other vehicle characteristics that could impact or detract from vehicle efficiency (*e.g.,* noise, vibration and harshness (NVH), drivability, durability, etc) were also considered during the generation of model inputs. However, they were not analyzed explicitly, with the expectation that manufacturers would ultimately be able to meet vehicle refinement levels necessary for commercial acceptability of these new technologies. These metrics, shown below in Table 3-9, include time at full load to reach given speeds (0-10 mph, 0-30 mph, etc), maximum grade capability, and distance traveled at a given time (e.g., after 3 seconds). Ultimately, the measure of equivalent performance is up to the reader or user of the Complex Systems tool. For EPA's analysis baseline vehicle 0-30 mph and 0-60 mph acceleration times were used as a benchmark for equivalent performance for the advanced vehicle packages. These estimated acceleration times are included in Table 3-11 through Table 3-18. Detailed results that include all performance metrics including those for baseline vehicles are provided in the full 2011 simulation report[1].

[u] The only exception to this is a subset of hybrids explicitly listed as "non-towing" vehicles. For further details and background, reference Section 1.3 of EPA's RIA.

Table 3-9: Vehicle performance metrics produced by the EASY5 model

Launch (WOT)	Passing (WOT)	Gradeability/ torque reserve
0-10 mph	30-50 mph	Max Speed @ 5% grade
0-30 mph	50-70 mph	Max Speed @ 10% grade
0-50 mph		Max Grade @ 70 mph (non-towing)
0-60 mph		Max Grade @ 60 mph (towing)
0-70 mph		
Distance @ 1.3 sec		
Distance @ 3 sec		
Speed @ 1.3 sec		
Speed @ 3 sec		

3.3.1.2.11 Review and revision of inputs

For any system modeling in which the results extend beyond the bounds of known physical examples (and therefore direct data validation is impossible), it is imperative that the inputs be carefully constructed and thoroughly examined to minimize the potential for uncertainty-related errors. Prior to coding of the models, Ricardo presented the following inputs for review and approval to EPA. For each topic, EPA reviewed the material considering the rationale of Ricardo's technical experts, the appropriateness of the inputs in relation to the assumed time horizon, the required emissions levels, and the known literature in the field today. Listed below are several of the model inputs that were jointly reviewed by Ricardo and EPA:

- Engine maps
    - Stoichiometric GDI turbo
    - Lean-burn GDI turbo
    - Cooled EGR turbo
    - Advanced diesel maps
- Transmission efficiency tables (by gear) including torque converter efficiency
- Engine warm-up strategy (cold start modifiers)
- Alternator regeneration strategy
- Transmission shift optimizer
- Engine friction reduction level
- P2 hybrid controls

- Input powersplit hybrid controls
- Hybrid battery assumptions
- Hybrid motor/generator efficiency maps

EPA technical experts recommended several changes and iterated with Ricardo to establish a consensus set of inputs that were plausible and met the ground rules of the project. Some of these changes resulted in higher efficiencies, while others lowered efficiency. Highlighted below are a few key examples, starting with development of the engine maps:

Engine maps carry perhaps the most significance of any of the sets of inputs needed to build vehicle simulation models. They provide the brake specific fuel consumption, or BSFC (typically in g/kWh) for a given engine speed and load. Typically these maps show an optimum speed and load band (or minimum BSFC "island") that is the most efficient condition in which to operate the engine. Ricardo generated engine maps for both the baseline vehicles (through benchmarking data) and proposed future engine maps for the various turbocharged and diesel engines. Figure 3-3 shows an example engine map for a baseline vehicle. It was constructed from EPA's analysis of a baseline vehicle model run output file. The contours represent lines of equivalent brake-specific fuel consumption.[v]

3.3.1.2.12 Engine Technologies

Ricardo developed the engines for the 2012-2025 timeframe in two ways. The first was to take current boosted SI research engines and project these would represent the level of performance which could be achieved by production engines in the 2020-2025 timeframe. The second method took current production Atkinson cycle SI and diesel engines and then included 2020-2025 timeframe technology improvements. Both methods extrapolated current engine design and development trend to the 2020-2025 timeframe. These current trends include engine friction reduction, improved fuel injection systems (e.g., spray guided for the SI, and higher injection pressures for the diesels), more advanced engine controls, and improved engine design for faster engine warm-up. EPA reviewed the engine maps recommended by Ricardo and generally concurred they were appropriate for the study time frame based on EPA's review of maps for current production engines and for research engines described in the literature.

[v] BSFC is measured in units of grams of fuel per kW-hour of energy and is an indicator of engine efficiency. Lower numbers indicate more efficient operating regions. As in this case, an engine typically has an "island' or region of best efficiency, in this case between 2000-3000 RPM and 150-180 Nm of torque. This island becomes much larger with the advent of advanced technologies such as boosting and downsizing, as well as advanced valvetrain technologies.

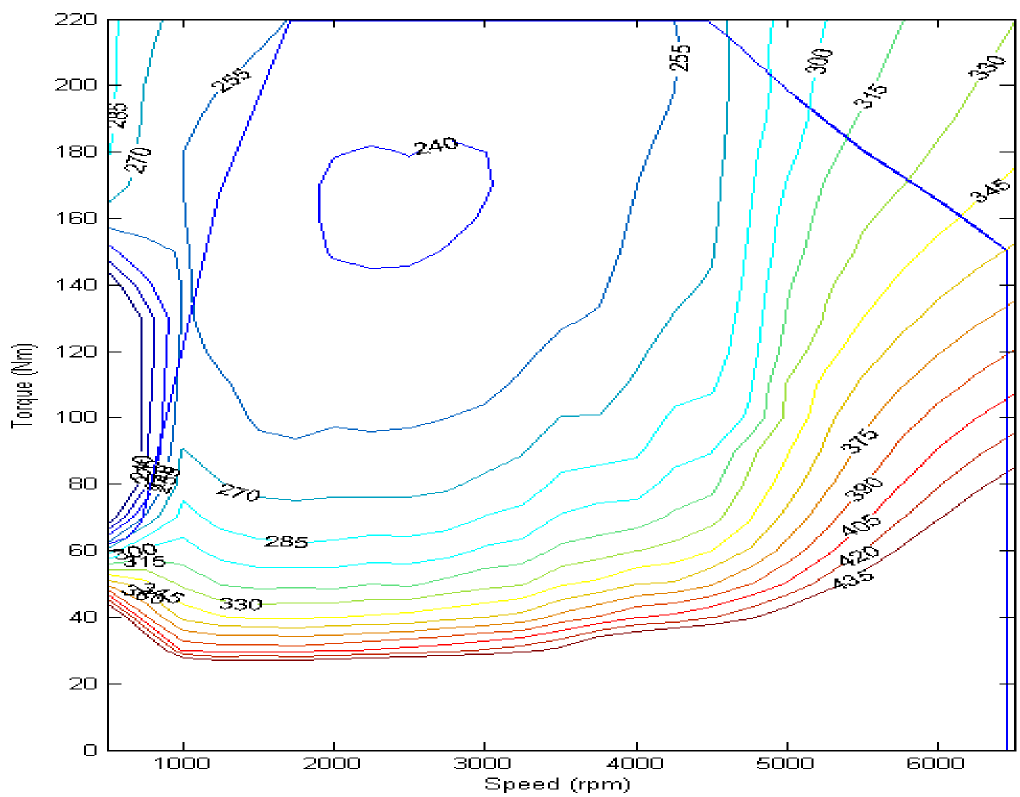


Figure 3-3: Example baseline engine BSFC map

3.3.1.2.12.1 Stoichiometric GDI

The original stoichiometric GDI map that Ricardo proposed was based on laboratory data they had published in 2007, showing a peak brake-specific load of just under 20 bar BMEP and a minimum BSFC of approximately 235 g/kWh, obtained using a compression ratio of 10.5:1.[26] However, based on input from manufacturers and from other, more recent published data on developmental and research engines, EPA asked Ricardo to raise the load capability of the engine to approximately 27 bar BMEP.[27,28,29,30] This allowed a greater degree of engine downsizing, which resulted in a downsizing of a 1.5 liter engine to a 0.74 liter engine for the nominal small car and a 5.4 liter to a 1.94 liter engine for the nominal large truck. A compression ratio of 10.5:1 was maintained for improved efficiency. At the same time, EPA asked that Ricardo eliminate the use of high-load enrichment, since water-cooled exhaust manifolds, in some cases integrated into the cylinder head, can be incorporated in next-generation designs to mitigate the need for fuel enrichment in lowering turbine inlet temperatures to 950 degrees C and thus avoid the added costs of high-temperature materials in the turbocharger.[31,32] By reducing the need for fuel enrichment fuel consumption is reduced over the more aggressive portions of the drive cycle, and PM emissions control at high load is improved.

3.3.1.2.13 Lean-burn GDI

Ricardo's initial lean-burn GDI map was based on their single-cylinder research engine data, in which they operated in lean stratified charge mode at all speeds and loads, without due consideration of the potential limitations in lean exhaust NOx aftertreatment systems. To address concerns in this area, EPA examined the boundaries of operation of lean-NOx catalysts, assuming that manufacturers would adopt either LNTs or metal-zeolite urea SCR systems. EPA therefore asked Ricardo to place a constraint on the maximum allowable catalyst space velocity (at high engine power) and exhaust gas temperature entering the catalyst (at high load, low engine speed conditions) to maintain catalyst efficiency at high load and to reduce thermal sintering of PGM under high-temperature, lean operating conditions. More specifically, EPA recommended that engine operation switch away from lean operation (at air/fuel equivalence ratios up to approximately $\lambda=1.5$) to stoichiometric operation at turbine outlet temperatures above 600C, and at total exhaust flows corresponding to space velocities of 60,000/hour, assuming a catalyst volume of 2.5 times engine displacement. This marginally diminished the engine brake thermal efficiency to stoichiometric GDI levels over this region of the map, but it provided more certainty that the engine would be able to adhere to the emissions levels as assumed in the project ground rules by the Advisory Committee. Figure 3-4 shows the engine speed and load region EPA proposed as suitable for lean stratified operation.

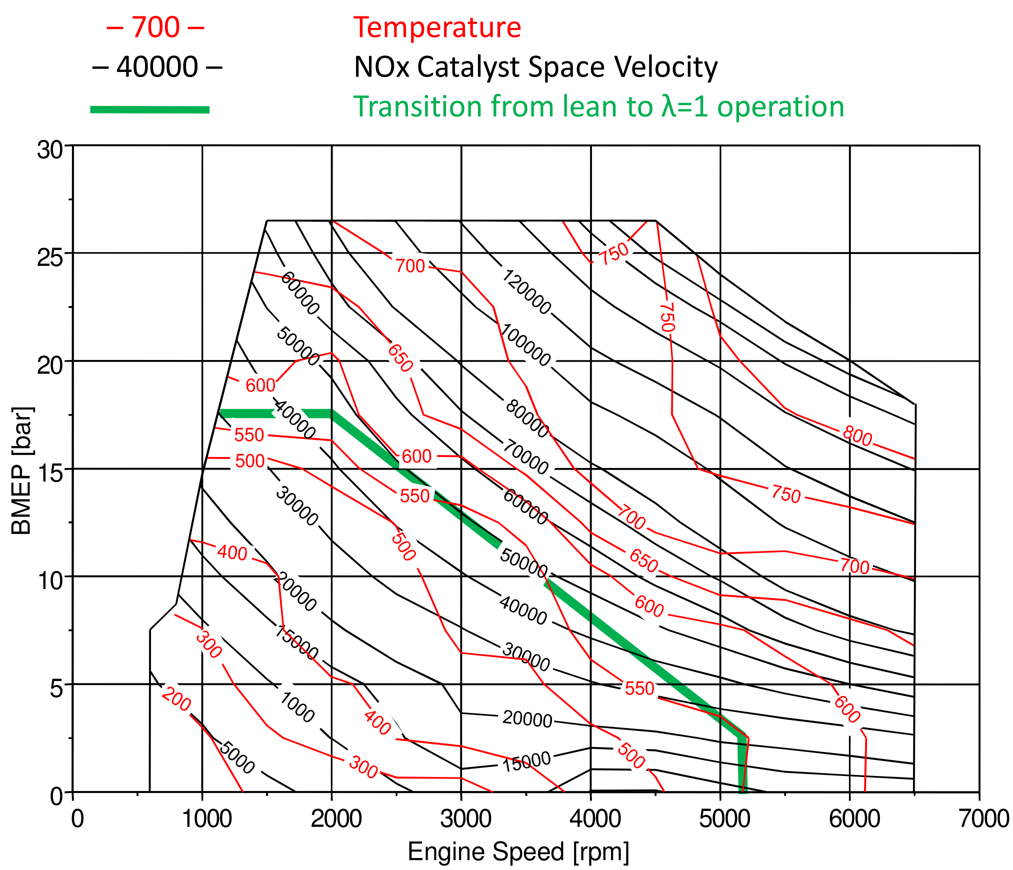


Figure 3-4 Proposed lean/stoichiometric operating threshold for lean-burn GDI engines

3.3.1.2.13.1 Cooled EGR GDI

EPA provided technical information from the literature which enabled Ricardo to assume a dual loop (both low pressure and high pressure EGR loops), cooled EGR system in addition to the stoichiometric turbocharged engine. The development of engine maps for this engine configuration was heavily informed by recently published data.[30,31,32,33]. Cooled EGR allowed the use of "λ=1" operation at the same compression ratio with more aggressive spark timing at high load and reduced pumping losses at part load while maintaining acceptable turbocharger inlet temperatures.

3.3.1.2.13.2 Motor/generator and power inverter efficiency maps

EPA recommended that Ricardo update the efficiency maps of the motor and generator (referred to as "electric machines" throughout the project), which they had proposed based on current best-in-class technology. The baseline motor/generator+inverter efficiency map is taken from a 2007 Camry and shown in Figure 3-5 below.

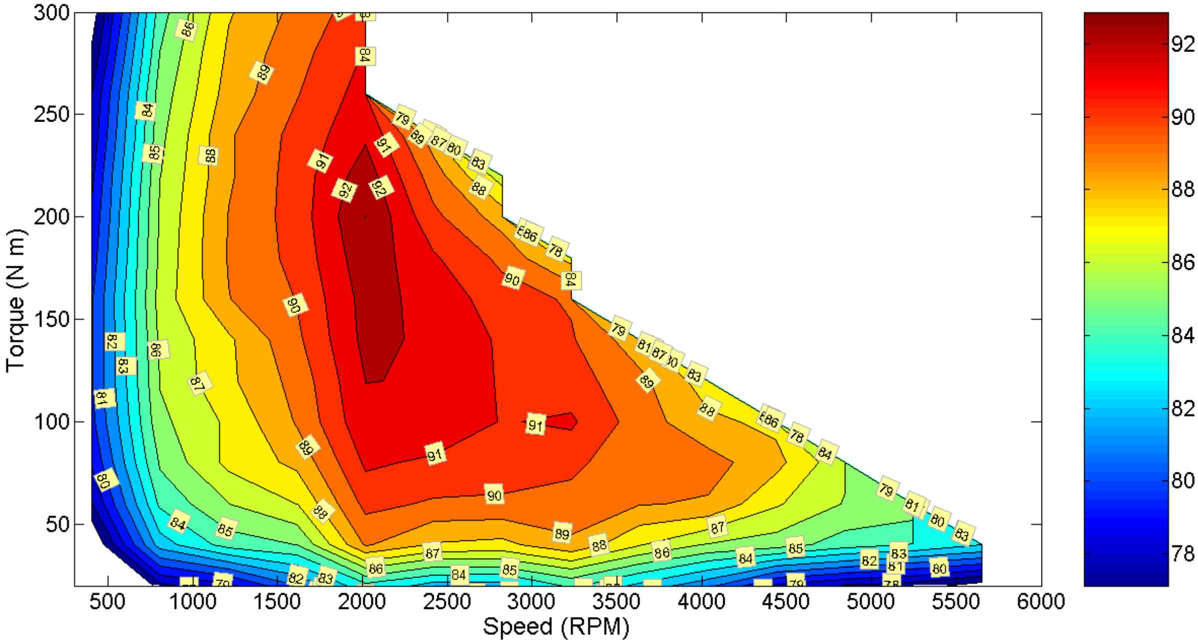


Figure 3-5: 2007 Camry Hybrid motor-inverter efficiency map (Burress, et al, 2008[34])

EPA requested that Ricardo provide their assessment of where they believed efficiency improvements might be made, based upon trends in research and development for both electric machines and power electronics. Ricardo and EPA generally agreed that these efficiency improvements were likely to be modest, particularly given the competitive pressures on manufacturers to reduce the cost of hybrid components. However, EPA and Ricardo assumed that today's best-in-class efficiency would likely be marginally improved through continuous incremental reductions in parasitic losses. To account for this, EPA and Ricardo agreed to reduce the losses in the motor/generator by 10% (in other words, raising the efficiency of a 90% efficient motor to 91%) and to reduce the losses in the power electronics by 25% (mainly through continued improvements in inverter development and electronic control systems).

3.3.1.2.13.3 Battery

Battery packs were assumed to consist of spinel LiMnO2 cathode chemistry, which is consistent with the current state of technology. EPA recommended a maximum usable state of charge of 40% (from 30% charge to 70% charge) be incorporated as an operating window in Ricardo's hybrid control logic. This range may increase in subsequent real world examples as manufacturers gain more field experience with long term battery durability. Additionally there will likely be more advances in battery construction and chemistry by 2025, so EPA considers these assumptions as conservative in view of the long term research currently underway in many battery research companies.

3.3.1.2.14 Additional Technologies Modeled by Ricardo for 2011 Report

The previous section discusses in detail those areas of the Ricardo simulation inputs which EPA provided recommendations to Ricardo on and which Ricardo agreed and made modifications to their initial suggestions. EPA did review modeling inputs for many other technologies modeled by Ricardo, but for which we generally agreed with the reasonableness of Ricardo's approach and did not request any changes. This section summarizes at a high level some of the additional technologies considered by Ricardo. Additional detail on these technologies is contained in the 2011 Ricardo final report.

Diesel engines - Ricardo started with existing production engines and identified technology advances that would lead to further advances in fuel consumption. These included many of the same technologies considered for advanced gasoline engines, such as engine friction reduction, improved fuel injection systems with higher injection pressures and more advanced controls, and better engine design to improve engine warm-up rate.

Transmission Technologies - Taking a systems approach in the vehicle simulation modeling, Ricardo also introduced additional transmission and driveline oriented technologies that may be pathways to increased efficiency. Some of these key technological enablers include: shift optimization schedules, advanced clutches, torque converter design and lockup schedules.

Automatic and Dual Clutch Transmissions - For the study timeframe, Ricardo assumed that eight-speed automatic transmissions will be in common use, as this supports more efficient operation, except for small cars, with energy losses expected to be about 20–33% lower than in current automatic transmissions. Energy losses in both wet clutch and dry clutch DCTs are expected to be 40–50% lower than in current automatic transmissions.

Transmission Shift Optimization - This advanced transmission shift optimization strategy tries to keep the engine operating near its most efficient point for a given power demand in effort to emulate a CVT. To protect against operating conditions out of normal range, several key parameters were identified, such as maximum engine speed, minimum lugging speed, and minimum delay between shifts. During development of this strategy, Ricardo estimated that fuel economy benefits of up to 5% can be obtained when compared to typical MY 2010 shift maps.

Torque Converter Technology – Ricardo utilized a lockup clutch model with a multi-damper system to provide earlier torque converter clutch engagement. The advanced automatic transmission applications allow torque converter lockup in any gear except first gear, up to sixth for the Small Car or eighth for the other LDV classes.

Shifting Clutch Technology - Shift clutch technology improves the thermal capacity of the shifting clutch to reduce plate count and lower clutch losses during shifting. Reducing the number of plates for the shifting process and reducing the hydraulic cooling requirements will increase the overall transmission efficiency for similar drivability characteristics.

Dry Sump Technology – A dry sump lubrication system provides benefits by keeping the rotating members out of oil, which reduces losses due to windage and churning. This approach will provide a GHG emissions benefit across all vehicle classes, with the best benefits at higher speed.

3.3.1.2.15 Baseline models built and run

Once all of the inputs were established, Ricardo built the baseline models: For these new (2010) baseline models Ricardo added a group of minor technologies, most of which already exist today in the market. The technologies included 12V stop-start, 6-speed automatic transmission, a high efficiency (70% efficient) alternator, and a strategy – "alternator regen" – that charges the 12V battery more aggressively by increasing the alternator field upon vehicle deceleration .

In the 2008 study Ricardo validated their baseline models with 2008 MY certification data. Ricardo's 2010 baseline model results provided effectiveness data for EPA to calibrate the lumped parameter model for some of the newly applied technologies. These technologies included alternator regeneration, high efficiency alternator, and stop-start.

For all model runs – the baselines and each of the advanced package nominal runs – EPA reviewed an extensive set of detailed intermediate output data for each model run. The parameters that were reviewed are shown in Table 3-10.

Table 3-10: Vehicle simulation output data reviewed

Ricardo outputs	**EPA-calculated outputs**
vehicle speed	engine operating point distribution
throttle position	engine load (BMEP)
engine torque	total accessory energy
engine power	round-trip battery loop losses
transmission input shaft torque	torque converter lockup time
wheel torque	total road load
transmission gear	total engine brake thermal energy
torque converter slip ratio	
current engine BSFC	**EPA-calculated metrics**
accessory power	cycle-average BSFC
engine speed	average brake thermal efficiency
road load	average engine power
N/V	average engine speed
electric power of motor generator	average engine torque
mechanical power of motor generator	# of idle-off events
motor generator speed	% of engine time off
motor generator torque	average accessory power
motor generator current	time in each gear
motor generator voltage	average gear efficiency
power flow through battery	average torque converter efficiency
battery state of charge	battery state-of-charge statistics
battery voltage	battery efficiency
regenerative braking power	% of vehicle braking energy recovered
vehicle foundation braking power	average motor efficiency
driver braking force	average generator efficiency
fuel mass flow rate	average motor and generator operating speeds
transmission mechanical loss power	average motor and generator operating torque
idle off status	total vehicle tractive energy

From this data, a set of summary statistics was generated to compare each baseline and nominal package run as a quality check. This information was used as the starting point in the dialogue between EPA and Ricardo to identify technical issues with the models. An example summary table (or "snapshot") for the 2010 Standard Car baseline is provided in Figure 3-6.

Vehicle	FTP	Hwy	Combined	US06	
CO2 Emissions (g/mi)	303.8	209.0	261.2	312.2	
Fuel Economy (mpg)	29.9	43.5	34.8	29.1	
2007 Base Vehicle CO2 (g/mi)	337.8	217.5	283.7		
% CO2 Reduction	10.1%	3.9%	7.9%		
Engine	**FTP**	**Hwy**	**Combined**	**US06**	
Avg Brake Thermal Efficiency	21.7%	27.8%	23.8%	30.6%	
Cycle Avg BSFC (g/kWh)	376	295	344	267	
Avg Engine Power (HP)	7.0	14.1	10.2	23.0	
Avg Engine Speed (RPM)	1993	1833	1921	2453	
Avg Load (BMEP-bar)	2.21	3.27	2.69	5.19	
Avg Torque (Nm)	42.1	62.5	51.3	99.1	for using Ricardo maps
Total Fuel (g)	1026.4	657.8	860.5	764.8	
Idle Off Events	20	1	n/a	5	
% Time Off	18.0%	0.5%	10.1%	6.5%	
Accessory Loss	0.0%	0.5%	0.3%	0.0%	% of FC
Avg accessory power (W)	8.2	198.0	93.6	12.4	
Avg BSFC temp mult (20F)	1.32	n/a	n/a	n/a	
Avg BSFC temp mult (75F)	1.20	n/a	n/a	n/a	
Transmission	**FTP**	**Hwy**	**Combined**	**US06**	
Time in gear 1	30%	2%	17%	13%	
Time in gear 2	9%	1%	5%	5%	
Time in gear 3	16%	2%	10%	7%	
Time in gear 4	27%	6%	18%	8%	
Time in gear 5	9%	35%	21%	10%	
Time in gear 6	9%	54%	29%	57%	
Time in gear 7	0%	0%	0%	0%	
Time in gear 8	0%	0%	0%	0%	
Avg. η (gear)	87.4%	88.0%	87.7%	87.9%	
Avg. η (TC)	88.9%	97.8%	92.9%	95.4%	
Avg. η (driveline)	77.7%	86%	81.5%	83.8%	
Battery	**FTP**	**Hwy**	**Combined**	**US06**	
SOC Avg	n/a	n/a	n/a	n/a	
Std Deviation	n/a	n/a	n/a	n/a	
Max SOC	n/a	n/a	n/a	n/a	
Min SOC	n/a	n/a	n/a	n/a	
Max SOC Swing	n/a	n/a	n/a	n/a	
Battery Efficiency (%)	n/a	n/a	n/a	n/a	
Average Voltage (V)	n/a	n/a	n/a	n/a	
Std Dev Voltage (V)	n/a	n/a	n/a	n/a	
Battery Energy Change (kWh)	0.00	0.00	0.00	0.00	
% of braking energy recovered	0.0%	0.0%	0.0%	0.0%	
%batt charge via brake recov	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
%batt charge via engine	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
MG1	**FTP**	**Hwy**	**Combined**	**US06**	**MG1=sun on planetary**
Test-Avg Motor Power (hp)	n/a	n/a	n/a	n/a	
Avg Motor Eff	n/a	n/a	n/a	n/a	
Avg Generator Eff	n/a	n/a	n/a	n/a	
Avg Torque-Motor (N-m)	n/a	n/a	n/a	n/a	
Avg Torque-Generator (N-m)	n/a	n/a	n/a	n/a	
Avg RPM-Motor	n/a	n/a	n/a	n/a	
Avg RPM-Generator	n/a	n/a	n/a	n/a	
Mech Energy-Motor (kWh)	0.00	0.00	0.00	0.00	Recovered energy returned to wheels
Mech Energy-Gen (kWh)	0.00	0.00	0.00	0.00	Gross recovered braking energy
MG2	**FTP**	**Hwy**	**Combined**	**US06**	**MG2=carrier (tractive)**
Avg Motor Power (hp)					
Avg Motor Eff	n/a	n/a	n/a	n/a	
Avg Generator Eff	n/a	n/a	n/a	n/a	
Avg Torque-Motor (N-m)	n/a	n/a	n/a	n/a	
Avg Torque-Generator (N-m)	n/a	n/a	n/a	n/a	
Avg RPM-Motor	n/a	n/a	n/a	n/a	
Avg RPM-Generator	n/a	n/a	n/a	n/a	
Mech Energy-Motor (kWh)	0.00	0.00	0.00	0.00	
Mech Energy-Gen (kWh)	0.00	0.00	0.00	0.00	
Round-trip MG efficiency	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	
Buck/Boost Converter	**FTP**	**Hwy**	**Combined**		
Avg Discharge Eff	n/a	n/a	n/a	n/a	
Avg Charging Eff	n/a	n/a	n/a	n/a	
Avg Bus Voltage (V)	n/a	n/a	n/a	n/a	
LHV (fuel)	44	kJ/g			
SG (fuel)	0.739				
Specific CO2	9087	g/gal			
Vehicle Energy Audit (kWh)	**FTP**	**Hwy**	**Combined**	**US06**	
Total fuel energy	12.54	8.04	10.52	9.35	
Total indicated energy	4.48	3.38	3.98	4.22	
Engine pumping energy	0.69	0.57	0.63	0.76	
Engine friction energy	0.86	0.48	0.69	0.52	
Engine braking energy	0.20	0.03	0.12	0.07	From alt regen braking (extra alternator load) x %
Total accessory energy	0.00	0.04	0.02	0.00	
Net brake thermal energy	**2.73**	**2.23**	**2.50**	**2.86**	
Torque converter losses	0.30	0.05	0.19	0.13	
Transmission losses	0.31	0.26	0.29	0.33	
Battery loop losses	0.00	0.00	0.00	0.00	
PE losses	0.00	0.00	0.00	0.00	
Losses to MG devices	0.00	0.00	0.00	0.00	
Total driveline losses	**0.61**	**0.31**	**0.47**	**0.46**	
Vehicle tractive energy	2.12	1.92	2.03	2.40	
Total road load energy	1.29	1.76	1.50	1.75	
Foundation braking energy	0.50	0.11	0.32	0.49	
Alternator regen decel energy	0.32	0.06	0.20	0.12	
Total reqd. braking energy	**0.82**	**0.16**	**0.53**	**0.62**	

Powertrain Architecture

Engine Disp L	Engine Torque Nm	Trans Type	# of gears	MG1 size kW	MG2 size kW	Battery size kWh
2.4	220	base auto	6	n/a	n/a	n/a

Performance Metrics

0-10mph	0-30mph	0-60mph	base 0-60	30-50mph	50-70mph	dist @ 3s
1.0	3.1	8.3	8.3	3.2	5.1	20.5

Shift Optimizer Evaluation Tables

Gear	Avg BMEP (bar)			Avg RPM		
	FTP	Hwy	US06	FTP	Hwy	US06
1	1.7	2.3	4.2	1421	1710	2155
2	3.0	3.9	7.1	2309	2463	2881
3	2.4	4.5	6.5	2088	2395	2974
4	1.6	3.1	6.7	2160	1978	3209
5	2.7	3.7	6.7	2028	1869	2561
6	2.3	2.8	4.0	1827	1737	2137
7	#DIV/0!	#DIV/0!	#DIV/0!	0	0	0
8	#DIV/0!	#DIV/0!	#DIV/0!	0	0	0

Gear	Avg BSFC (g/kWh)			Total Energy (%)		
	FTP	Hwy	US06	FTP	Hwy	US06
1	338	330	256	16%	1%	8%
2	328	282	255	15%	1%	9%
3	359	268	264	21%	3%	10%
4	482	298	265	24%	7%	10%
5	361	279	251	12%	42%	16%
6	388	311	279	11%	46%	49%
7	0	0	0	0%	0%	0%
8	0	0	0	0%	0%	0%

Figure 3-6 Sample output summary sheet for Standard Car (Camry) baseline

Summary statistics were used as a first-order quality check on the model. Sample checks included:

- were average engine speed and load within or close to the best BSFC region for the vehicle's engine map?
- was transmission gear distribution reasonable and consistent between engine types?

3.3.1.2.16 Nominal runs

The Ricardo "nominal" runs refer to the initial set of vehicle simulation models built for each vehicle architecture and vehicle class. These runs were used by EPA to assess the validity of the detailed model outputs (and hence the models themselves) prior to proceeding with the full design of experiment runs. Table 3-11 shows the summary results from the raw nominal runs for the conventional stop-start vehicles (including 12V stop-start, 70% efficient alternator, shift optimizer and alternator regen, as well as a 3.5% improvement due to engine friction reduction). Conventional automatic transmissions are assumed in all nominal runs. No road load reductions are included in these results. GHG reductions are in reference to the 2008 baseline vehicles.

Table 3-11: Nominal Conventional Stop-Start modeling results

Vehicle Class	Engine Type	Displ. L	Torque Nm	Trans Type	FTP mpg	HW mpg	**Comb mpg**	0-30mph s	0-60mph s	**% GHG Reduction**
Small Car	STDI	0.74	157	AT6	53.2	55.1	**54.0**	4.0	10.0	**20%**
	LBDI	0.74	157	AT6	55.1	56.0	**55.5**	4.0	10.0	**22%**
	EGRB	0.74	157	AT6	55.1	57.4	**56.1**	4.0	10.0	**23%**
	2020 Diesel	1.23	221	AT6	55.8	59.4	**57.4**	3.7	9.8	**16%**
Std Car	STDI	1.04	220	AT8	44.8	54.5	**48.7**	3.1	8.5	**28%**
	LBDI	1.04	220	AT8	46.6	55.5	**50.2**	3.1	8.5	**31%**
	EGRB	1.04	220	AT8	46.4	56.7	**50.5**	3.1	8.5	**31%**
Large Car	STDI	1.41	298	AT8	37.1	43.2	**39.6**	3.0	7.4	**31%**
	LBDI	1.41	298	AT8	38.8	44.0	**41.0**	3.0	7.4	**33%**
	EGRB	1.41	298	AT8	38.6	44.9	**41.2**	3.0	7.4	**33%**
	2020 Diesel	2.85	503	AT8	38.2	46.5	**41.5**	2.9	7.5	**27%**
Small MPV	STDI	1.13	239	AT8	38.8	42.6	**40.4**	3.3	8.9	**25%**
	LBDI	1.13	239	AT8	40.3	43.1	**41.5**	3.3	8.9	**27%**
	EGRB	1.13	239	AT8	40.3	44.4	**42.0**	3.3	8.9	**28%**
Large MPV	STDI	1.31	277	AT8	34.8	39.2	**36.7**	3.2	8.6	**31%**
	LBDI	1.31	277	AT8	36.0	39.8	**37.6**	3.2	8.6	**33%**
	EGRB	1.31	277	AT8	36.2	40.9	**38.2**	3.2	8.6	**34%**
	2020 Diesel	2.61	460	AT8	37.3	43.3	**39.8**	3.0	8.6	**30%**
Truck	STDI	1.94	410	AT8	23.8	26.6	**25.0**	3.0	8.1	**26%**
	LBDI	1.94	410	AT8	24.6	27.0	**25.6**	3.0	8.1	**28%**
	EGRB	1.94	410	AT8	24.8	27.7	**26.0**	3.0	8.1	**29%**
	2020 Diesel	4.28	694	AT8	26.4	30.4	**28.1**	2.9	8.0	**26%**
HD Truck	STDI	2.3	486	AT8	16.5	18.3	**17.3**	3.2	9.8	**27%**
	LBDI	2.3	486	AT8	16.8	18.4	**17.5**	3.2	9.8	**28%**
	EGRB	2.3	486	AT8	17.2	19.1	**18.0**	3.2	9.8	**30%**
	2020 Diesel	6.6	895	AT8	19.8	21.5	**20.5**	2.9	8.8	**31%**

Table 3-12 shows the results from the nominal runs for the P2 hybrid vehicles. Dual-clutch transmissions are assumed in all nominal runs. No road load reductions are included in these results. GHG reductions are in reference to the 2008 baseline vehicles.

Table 3-12: Nominal P2 Hybrid modeling results

Vehicle Class	Engine Type	Displ. L	Torque Nm	EM size kW	Batt size kWh	Trans Type	FTP mpg	HW mpg	**Comb mpg**	0-30mph s	0-60mph s	**% GHG Reduction**
Small Car	STDI	0.59	124	14	0.70	DCT6	68.2	57.3	**62.8**	3.8	9.6	**31%**
	LBDI	0.59	124	14	0.70	DCT6	68.4	57.7	**63.2**	3.8	9.6	**31%**
	EGRB	0.59	124	14	0.70	DCT6	70.2	59.9	**65.2**	3.8	9.6	**33%**
	ATKCS	1.66	138	14	0.70	DCT6	70.8	59.0	**64.9**	3.7	10.0	**33%**
	ATKDVA	1.66	138	14	0.70	DCT6	71.7	60.5	**66.2**	3.7	10.0	**35%**
Std Car	STDI	0.83	176	24	1.00	DCT8	61.9	57.2	**59.7**	3.6	8.6	**42%**
	LBDI	0.83	176	24	1.00	DCT8	62.9	58.0	**60.6**	3.6	8.6	**42%**
	EGRB	0.83	176	24	1.00	DCT8	65.1	59.7	**62.5**	3.6	8.6	**44%**
	ATKCS	2.4	200	24	1.00	DCT8	64.6	59.7	**62.3**	3.4	8.6	**44%**
	ATKDVA	2.4	200	24	1.00	DCT8	65.9	61.0	**63.6**	3.4	8.6	**45%**
Large Car	STDI	1.13	238	28	1.10	DCT8	49.8	46.5	**48.2**	3.4	7.7	**43%**
	LBDI	1.13	238	28	1.10	DCT8	50.4	46.8	**48.7**	3.4	7.7	**44%**
	EGRB	1.13	238	28	1.10	DCT8	51.7	48.3	**50.1**	3.4	7.7	**45%**
	ATKCS	3.8	317	28	1.10	DCT8	49.9	46.2	**48.1**	3.0	7.1	**43%**
	ATKDVA	3.8	317	28	1.10	DCT8	51.1	47.4	**49.4**	3.0	7.1	**44%**
Small MPV	STDI	0.9	190	20	1.10	DCT8	50.1	44.2	**47.2**	3.9	9.4	**36%**
	LBDI	0.9	190	20	1.10	DCT8	50.8	44.5	**47.8**	3.9	9.4	**36%**
	EGRB	0.9	190	20	1.10	DCT8	52.0	46.1	**49.2**	3.9	9.4	**38%**
	ATKCS	2.6	217	20	1.10	DCT8	52.9	45.5	**49.3**	3.7	9.3	**38%**
	ATKDVA	2.6	217	20	1.10	DCT8	54.1	46.8	**50.5**	3.7	9.3	**40%**
Large MPV	STDI	1.05	221	25	1.15	DCT8	47.7	42.2	**45.0**	3.8	9.1	**44%**
	LBDI	1.05	221	25	1.15	DCT8	47.4	42.6	**45.1**	3.8	9.1	**44%**
	EGRB	1.05	221	25	1.15	DCT8	47.6	43.0	**45.4**	3.8	9.1	**44%**
	ATKCS	3.15	263	25	1.15	DCT8	48.3	42.4	**45.4**	3.6	8.8	**45%**
	ATKDVA	3.15	263	25	1.15	DCT8	48.8	43.5	**46.2**	3.6	8.8	**45%**
Truck	STDI	1.55	327	50	1.50	DCT8	32.5	28.4	**30.5**	3.3	7.9	**39%**
	LBDI	1.55	327	50	1.50	DCT8	33.0	28.6	**30.9**	3.3	7.9	**40%**
	EGRB	1.55	327	50	1.50	DCT8	33.8	29.6	**31.8**	3.3	7.9	**42%**
	ATKCS	4.6	384	50	1.50	DCT8	33.2	29.0	**31.2**	3.1	7.8	**40%**
	ATKDVA	4.6	384	50	1.50	DCT8	33.9	29.7	**31.8**	3.1	7.8	**42%**

Table 3-13 shows the results from the nominal runs for the input powersplit vehicles[w]. No road load reductions are included in these results. GHG reductions are in reference to the 2008 baseline vehicles.

[w] While input powersplit hybrids remain a very likely hybrid architecture choice for some manufacturers, the Agencies focused on P2 hybrids compared to powersplits due to their apparent cost-effectiveness advantage in future years. As a result the powersplit nominal runs did not receive the same level of engineering scrutiny as the P2 hybrid nominal runs.

Table 3-13: Nominal Powersplit hybrid modeling results

Vehicle Class	Engine Type	Displ. L	Torque Nm	EM size kW	Batt size kWh	Trans Type	FTP mpg	HW mpg	Comb mpg	0-30mph s	0-60mph s	% GHG Reduction
Small Car	STDI	0.59	124	14	0.70	PS	64.7	57.2	**61.1**	4.8	10.4	**29%**
	LBDI	0.59	124	14	0.70	PS	65.8	57.4	**61.7**	4.8	10.4	**30%**
	EGRB	0.59	124	14	0.70	PS	67.7	60.1	**64.0**	4.8	10.4	**32%**
	ATKCS	1.66	138	14	0.70	PS	64.2	59.5	**62.0**	4.7	9.8	**30%**
	ATKDVA	1.66	138	14	0.70	PS	67.3	60.0	**63.8**	4.7	9.8	**32%**
Std Car	STDI	0.83	176	80	1.00	PS	55.6	51.7	**53.8**	3.7	8.7	**35%**
	LBDI	0.83	176	80	1.00	PS	57.9	53.5	**55.8**	3.7	8.7	**38%**
	EGRB	0.83	176	80	1.00	PS	58.0	54.8	**56.5**	3.7	8.7	**38%**
	ATKCS	2.4	200	80	1.00	PS	53.3	51.7	**52.6**	3.6	8.0	**34%**
	ATKDVA	2.4	200	80	1.00	PS	56.4	53.3	**55.0**	3.6	8.0	**37%**
Large Car	STDI	1.13	238	28	1.10	PS	46.6	42.0	**44.4**	3.2	7.8	**38%**
	LBDI	1.13	238	28	1.10	PS	48.0	41.8	**45.0**	3.2	7.8	**39%**
	EGRB	1.13	238	28	1.10	PS	47.9	43.6	**45.9**	3.2	7.8	**40%**
	ATKCS	3.8	317	28	1.10	PS	40.3	38.7	**39.6**	3.2	7.1	**31%**
	ATKDVA	3.8	317	28	1.10	PS	43.0	40.8	**42.0**	3.2	7.1	**35%**
Small MPV	STDI	0.9	190	20	1.10	PS	49.1	42.2	**45.8**	4.7	10.3	**33%**
	LBDI	0.9	190	20	1.10	PS	50.8	42.7	**46.8**	4.7	10.3	**35%**
	EGRB	0.9	190	20	1.10	PS	51.3	44.9	**48.2**	4.7	10.3	**37%**
	ATKCS	2.6	217	20	1.10	PS	44.3	39.6	**42.1**	4.6	9.1	**28%**
	ATKDVA	2.6	217	20	1.10	PS	49.3	42.3	**45.9**	4.6	9.1	**34%**
Large MPV	STDI	1.05	221	25	1.15	PS	44.8	39.3	**42.1**	4.3	9.7	**40%**
	LBDI	1.05	221	25	1.15	PS	45.7	40.6	**43.3**	4.3	9.7	**42%**
	EGRB	1.05	221	25	1.15	PS	47.0	41.5	**44.4**	4.3	9.7	**43%**
	ATKCS	3.15	263	25	1.15	PS	41.7	38.6	**40.3**	4.2	8.8	**37%**
	ATKDVA	3.15	263	25	1.15	PS	44.3	39.6	**42.0**	4.2	8.8	**40%**

3.3.1.2.17 Response Surface Model matrix runs

After the nominal runs were completed according to the agreed-upon methodology, Ricardo set up a design of experiment matrix for each vehicle architecture. The continuously swept variables were randomized in a Latin hypercube fashion to achieve a representative sample within each matrix (reference the Ricardo report for more details on the complex systems modeling approach used). After a data review and removal of runs with errors[x] (as needed) Ricardo then generated Response Surface Models (RSM) for use in the complex systems tool. EPA used the tool to evaluate a range of potential engine displacements, final drive ratios and electric motor sizes (hybrids only) for each vehicle package, in an effort to find the combination that would provide the greatest effectiveness while meeting EPA's definition of "equivalent performance".

[x] e.g., model runs in which the vehicles were underpowered to the point where they could not follow the prescribed vehicle speed trace, rendering an invalid test or "error". These configurations were then excluded from the data sets.

3.3.1.2.18 Equivalent performance definition

The Ricardo output data provides several performance metrics, as discussed in 3.3.1.2.10. For simplicity, EPA assumed that a range of acceleration times for both a 0-60 mph test and also a 0-30 mph test (emphasizing launch character) would provide a simple yet representative measure of a vehicle's equivalent performance. A range was chosen rather than assuming a single point value equal to the baseline. This provided more acceptable data points and reduced error due to "noise" in the datasets. The acceptable acceleration times were as follows with respect to the baseline:

0-60 mph: 5 percent slower to 15 percent faster as compared to baseline

0-30 mph: 10 percent slower to 20 percent faster as compared to baseline

The range above reflects a deviation from the actual baseline value that is well within the normal variation of acceleration times for different vehicle models within a given vehicle class.

3.3.1.2.19 Treatment of "turbo lag" in performance runs for turbocharged engines

A common critique of comparisons of the modeled performance of highly turbocharged engines with naturally-aspirated engines is that consideration must be given to the delay in producing full engine load associated with the turbocharger, commonly referred to as "turbo lag". In technical discussions, Ricardo's engine experts assured EPA that the dual-sequential designs of the turbocharger systems in the engines in this study should mitigate most of this phenomenon often seen on older-model vehicles. However, due to the heavy reliance on turbocharged engines as a significant source of motive force for the high BMEP engines evaluated in this project, EPA took this sensitivity further into account.

Ricardo's initial model of WOT operation was based on a steady-state model of engine torque, assuming that the engine would be able to instantaneously reach a desired level of output torque, without consideration of the intake manifold filling dynamics or the mechanical inertia of the engine. EPA raised this as an issue, more in terms of properly representing vehicle performance than for effectiveness differences. EPA reviewed its own engine development data and proposed a somewhat conservative time constant for both the naturally aspirated engines (0.3 s) and the turbocharged engines (1.5 s), to apply to the engine torque response in the vehicle performance runs (these are shown below in Figure 3-7). In turn, Ricardo recalculated the acceleration times for the 0-30 and 0-60 mph runs to reflect the slower time constants. As a result, EPA used these two performance metrics exclusively in determining "equivalent performance". A transient engine/turbo model would have improved the accuracy of the model somewhat; however, it was beyond the scope of this project.

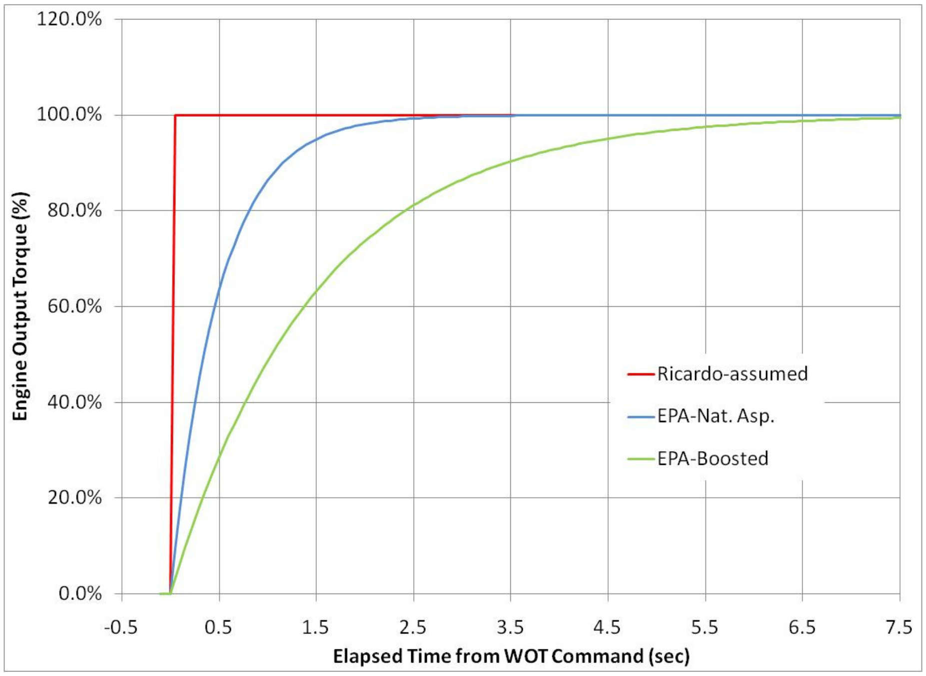


Figure 3-7: EPA proposed time constants and resulting effect on torque rise time for turbocharging

3.3.1.2.20 Treatment of engine response and "turbo lag" in cycle simulations and control logic algorithms

The EASY5 model used in the Ricardo simulations included engine and driveline inertia effects which account for some of the real-world transient torque delays. However, the simulation modeling did not include an adjustment to account for transient engine response delays (e.g. inclusion of time constant offsets), to simulate naturally aspirated and turbocharged engine response delays associated with intake manifold gas dynamics and turbocharger response delay. Consideration of engine response delay might affect how transmission shift optimization control logic and advanced HEV control logic is structured, and potentially affect GHG and fuel economy projections, particularly for boosted and downsized engines. EPA and Ricardo believe that the impact is small over the city and highway fuel economy test cycles. The agencies sought comment on the fuel economy impact of transient delays over the test cycles not accounted for in the Ricardo modeling, but there were no comments received, so the agencies have made no changes in this respect for the final rule analysis.

3.3.1.2.21 "Equivalent performance" results for conventional stop-start vehicles

The following tables show the results from the complex systems tool, when displacement, final drive ratio and electric motor size are varied to optimize GHG and fuel consumption reduction effectiveness at equivalent performance for conventional stop-start, P2 and powersplit hybrids. Most of the vehicles show little change in performance between the nominal runs and the equivalent performance results from the complex systems tool. Table

3-14 through Table 3-18 illustrate the various effects of changing road loads on the various vehicle package configurations. Table 3-14, Table 3-16, and Table 3-16, respectively, show the equivalent performance results for the conventional stop-start (for both automatic transmissions and DCTs) and the P2 hybrid vehicles (modeled only as DCTs). No road load reductions are included in Table 3-14 through Table 3-16. For comparison, a second set of tables (Table 3-17 and Table 3-18) give equivalent performance results for conventional stop-start vehicles and P2 hybrids, each including example road load reductions[y] of 20% mass reduction, 20% aerodynamic drag reduction and 10% rolling resistance reduction.

The package effectiveness results from the equivalent performance runs were used in the datasets to calibrate the individual technology effectiveness values within the lumped parameter model. The development of the lumped parameter model is described in detail in Section 1.5 of EPA's RIA.

Table 3-14: Equivalent performance results for conventional-stop start vehicles (no road load reductions)

Vehicle Class	Engine Type	Displ. L	Torque Nm	Trans Type	FTP mpg	HW mpg	**Comb mpg**	0-30mph s	0-60mph s	**% GHG Reduction**
Small Car	STDI	0.86	183	AT6	53.1	56.5	**54.6**	4.1	9.1	**21%**
	LBDI	0.90	190	AT6	56.3	57.5	**56.9**	4.1	8.9	**24%**
	EGRB	0.72	154	AT6	55.2	59.1	**56.9**	4.1	10.1	**24%**
	2020 Diesel	1.19	213	AT6	57.3	64.2	**60.2**	3.8	10.0	**20%**
Std Car	STDI	1.13	240	AT8	44.4	54.5	**48.5**	2.9	7.9	**28%**
	LBDI	1.26	266	AT8	47.0	56.0	**50.6**	2.8	7.2	**31%**
	EGRB	1.09	230	AT8	46.2	57.0	**50.5**	3.1	8.3	**31%**
Large Car	STDI	1.48	314	AT8	37.0	43.4	**39.6**	3.0	7.2	**31%**
	LBDI	1.50	317	AT8	39.2	44.3	**41.3**	2.9	7.1	**34%**
	EGRB	1.56	330	AT8	38.6	45.0	**41.2**	3.0	7.0	**34%**
	2020 Diesel	2.57	454	AT8	39.1	47.1	**42.3**	3.0	8.1	**28%**
Small MPV	STDI	1.32	280	AT8	38.9	42.4	**40.4**	3.2	8.0	**25%**
	LBDI	1.41	297	AT8	41.1	43.9	**42.3**	3.2	7.7	**28%**
	EGRB	1.40	296	AT8	40.0	45.1	**42.1**	3.2	7.7	**28%**
Large MPV	STDI	1.57	332	AT8	34.8	39.5	**36.8**	2.9	7.4	**31%**
	LBDI	1.51	319	AT8	36.2	40.6	**38.0**	3.0	7.7	**34%**
	EGRB	1.47	312	AT8	36.4	40.9	**38.3**	2.9	7.6	**34%**
	2020 Diesel	2.74	483	AT8	36.7	44.0	**39.7**	3.0	8.4	**29%**
Truck	STDI	2.30	486	AT8	24.0	26.8	**25.2**	2.8	7.0	**26%**
	LBDI	2.06	435	AT8	25.0	26.9	**25.8**	2.9	7.6	**28%**
	EGRB	2.28	482	AT8	24.8	28.1	**26.2**	2.9	7.2	**29%**
	2020 Diesel	4.12	669	AT8	26.8	31.2	**28.6**	2.9	8.3	**28%**
HD Truck	STDI	2.72	575	AT8	16.6	18.6	**17.4**	3.0	8.4	**27%**
	LBDI	2.69	568	AT8	17.2	18.8	**17.9**	2.9	8.4	**29%**
	EGRB	2.71	573	AT8	17.3	19.4	**18.2**	2.9	8.4	**30%**
	2020 Diesel	5.64	764	AT8	21.0	24.6	**22.5**	3.2	10.3	**37%**

[y] Note that in the regulatory fleet analysis, levels of road load reduction technologies (e.g., mass reduction) will vary by vehicle class. These tables are illustrative in nature.

Table 3-15: Equivalent performance results for conventional-stop start vehicles with DCT transmissions (no road load reductions)

Vehicle Class	Engine Type	Displ. L	Torque Nm	Trans Type	FTP mpg	HW mpg	**Comb mpg**	0-30mph s	0-60mph s	**% GHG Reduction**
Small Car	STDI	0.91	193	dry DCT6	55.0	58.8	**56.7**	3.9	8.6	**23%**
	LBDI	0.92	196	dry DCT6	58.0	59.8	**58.8**	3.9	8.5	**26%**
	EGRB	0.89	188	dry DCT6	57.2	61.3	**59.0**	3.9	8.7	**27%**
	2020 Diesel	1.13	204	dry DCT6	61.4	69.4	**64.8**	3.9	10.4	**26%**
Std Car	STDI	1.08	229	dry DCT8	46.4	55.0	**49.9**	3.1	8.0	**30%**
	LBDI	1.29	273	dry DCT8	48.7	57.5	**52.3**	3.0	7.1	**33%**
	EGRB	1.17	248	dry DCT8	48.1	57.6	**51.9**	3.0	7.6	**33%**
Large Car	STDI	1.53	324	dry DCT8	38.4	44.0	**40.7**	2.9	6.8	**33%**
	LBDI	1.66	352	dry DCT8	40.5	45.4	**42.6**	2.9	6.5	**36%**
	EGRB	1.48	313	dry DCT8	40.0	45.6	**42.3**	3.0	7.0	**35%**
	2020 Diesel	2.44	431	dry DCT8	41.0	48.4	**44.0**	3.0	8.1	**31%**
Small MPV	STDI	1.30	276	dry DCT8	40.1	43.6	**41.6**	3.1	7.7	**27%**
	LBDI	1.32	280	dry DCT8	42.1	44.7	**43.2**	3.2	7.7	**30%**
	EGRB	1.33	282	dry DCT8	41.7	45.6	**43.3**	3.1	7.6	**30%**
Large MPV	STDI	1.53	324	wet DCT8	36.0	40.2	**37.8**	3.1	7.4	**33%**
	LBDI	1.56	330	wet DCT8	38.0	41.1	**39.4**	3.0	7.3	**36%**
	EGRB	1.56	330	wet DCT8	37.6	41.8	**39.4**	3.0	7.3	**36%**
	2020 Diesel	2.42	427	wet DCT8	39.2	45.2	**41.7**	3.1	9.0	**33%**
Truck	STDI	2.23	472	wet DCT8	24.8	27.1	**25.8**	3.0	7.1	**28%**
	LBDI	2.26	478	wet DCT8	25.9	27.7	**26.7**	3.0	7.0	**31%**
	EGRB	2.25	475	wet DCT8	25.8	28.1	**26.8**	3.0	7.0	**31%**
	2020 Diesel	3.78	613	wet DCT8	28.1	32.1	**29.8**	3.0	8.6	**31%**
HD Truck	STDI	2.55	538	wet DCT8	17.3	18.1	**17.6**	3.1	8.5	**28%**
	LBDI	2.62	554	wet DCT8	17.8	18.7	**18.2**	3.1	8.4	**30%**
	EGRB	2.58	544	wet DCT8	18.0	19.0	**18.4**	3.1	8.5	**31%**
	2020 Diesel	5.45	739	wet DCT8	21.8	24.2	**22.8**	3.3	10.3	**38%**

Table 3-16: Equivalent performance results for P2 hybrids (no road load reductions)

Vehicle Class	Engine Type	Displ. L	Torque Nm	EM size kW	Batt size kWh	Trans Type	FTP mpg	HW mpg	Comb mpg	0-30mph s	0-60mph s	% GHG Reduction
Small Car	STDI	0.68	144	21	0.70	DCT6	68.9	58.7	**63.9**	3.7	8.5	**32%**
	LBDI	0.68	144	21	0.70	DCT6	70.1	59.2	**64.7**	3.7	8.5	**33%**
	EGRB	0.67	142	21	0.70	DCT6	72.0	61.2	**66.7**	3.7	8.5	**35%**
	ATKCS	1.72	143	17	0.70	DCT6	72.0	60.8	**66.5**	3.9	9.6	**35%**
	ATKDVA	1.68	140	19	0.70	DCT6	74.4	62.0	**68.2**	3.8	9.6	**36%**
Std Car	STDI	1.00	213	26	1.00	DCT8	62.2	57.7	**60.1**	3.4	7.9	**42%**
	LBDI	0.95	202	27	1.00	DCT8	63.2	58.3	**60.9**	3.4	8.0	**43%**
	EGRB	1.04	219	26	1.00	DCT8	64.8	60.4	**62.7**	3.4	7.8	**44%**
	ATKCS	2.54	212	27	1.00	DCT8	64.6	59.5	**62.2**	3.4	8.6	**44%**
	ATKDVA	2.31	193	28	1.00	DCT8	65.7	60.7	**63.4**	3.4	8.7	**45%**
Large Car	STDI	1.39	292	29	1.10	DCT8	50.6	47.3	**49.1**	3.3	7.2	**44%**
	LBDI	1.37	289	29	1.10	DCT8	51.3	47.9	**49.7**	3.4	7.3	**45%**
	EGRB	1.38	291	29	1.10	DCT8	52.6	49.0	**50.9**	3.4	7.2	**46%**
	ATKCS	3.73	311	30	1.10	DCT8	48.6	46.1	**47.5**	3.2	7.5	**42%**
	ATKDVA	3.33	278	30	1.10	DCT8	50.7	47.7	**49.3**	3.3	8.0	**44%**
Small MPV	STDI	1.40	295	34	1.10	DCT8	52.3	45.5	**49.0**	3.6	8.1	**38%**
	LBDI	1.39	293	37	1.10	DCT8	53.0	45.9	**49.6**	3.5	8.0	**39%**
	EGRB	1.41	297	38	1.10	DCT8	54.4	47.2	**50.9**	3.4	7.9	**40%**
	ATKCS	3.87	322	38	1.10	DCT8	53.6	46.2	**50.0**	3.6	9.0	**39%**
	ATKDVA	3.59	299	39	1.10	DCT8	55.2	47.4	**51.4**	3.7	9.3	**41%**
Large MPV	STDI	1.31	276	30	1.15	DCT8	48.5	42.3	**45.5**	3.2	7.4	**45%**
	LBDI	1.30	274	31	1.15	DCT8	49.0	42.6	**45.9**	3.2	7.4	**45%**
	EGRB	1.29	272	32	1.15	DCT8	49.2	42.7	**46.0**	3.2	7.5	**45%**
	ATKCS	3.13	262	34	1.15	DCT8	48.0	42.3	**45.3**	3.2	8.2	**44%**
	ATKDVA	3.00	250	34	1.15	DCT8	48.5	43.0	**45.9**	3.2	8.3	**45%**
Truck	STDI	1.87	394	50	1.50	DCT8	33.3	29.0	**31.2**	3.3	7.3	**40%**
	LBDI	1.92	404	48	1.50	DCT8	33.6	29.3	**31.5**	3.4	7.2	**41%**
	EGRB	1.92	405	48	1.50	DCT8	34.6	30.2	**32.4**	3.3	7.2	**43%**
	ATKCS	5.34	445	53	1.50	DCT8	32.3	28.8	**30.6**	3.1	7.2	**39%**
	ATKDVA	5.34	445	56	1.50	DCT8	32.7	29.4	**31.1**	3.0	7.1	**40%**

Table 3-17 Equivalent performance results for conventional-stop start vehicles (with 20% mass, 20% aerodynamic drag and 10% rolling resistance reductions)

Vehicle Class	Engine Type	Displ. L	Torque Nm	Trans Type	FTP mpg	HW mpg	Comb mpg	0-30mph s	0-60mph s	% GHG Reduction
Small Car	STDI	0.68	145	AT6	65.0	70.0	**67.2**	4.1	9.2	**35%**
	LBDI	0.89	189	AT6	68.9	72.4	**70.4**	4.2	8.4	**38%**
	EGRB	0.69	146	AT6	67.6	73.1	**70.0**	4.1	9.2	**38%**
	2020 Diesel	0.91	164	AT6	71.8	83.2	**76.5**	3.7	10.4	**37%**
Std Car	STDI	1.04	220	AT8	53.9	67.6	**59.3**	2.9	7.2	**41%**
	LBDI	1.27	268	AT8	57.3	70.6	**62.6**	2.8	6.4	**44%**
	EGRB	0.98	207	AT8	56.2	70.1	**61.7**	3.0	7.6	**43%**
Large Car	STDI	1.00	212	AT8	46.5	53.8	**49.5**	3.1	8.1	**45%**
	LBDI	1.49	315	AT8	48.4	55.0	**51.2**	3.0	6.5	**46%**
	EGRB	1.00	212	AT8	48.5	55.9	**51.6**	3.1	8.1	**47%**
	2020 Diesel	2.05	362	AT8	48.5	59.7	**53.0**	3.0	8.1	**42%**
Small MPV	STDI	1.20	253	AT8	46.3	51.8	**48.6**	3.2	7.4	**37%**
	LBDI	1.40	296	AT8	49.1	53.5	**51.0**	3.3	6.9	**40%**
	EGRB	1.13	238	AT8	48.4	53.6	**50.6**	3.2	7.7	**40%**
Large MPV	STDI	1.00	212	AT8	42.4	46.8	**44.3**	3.2	8.8	**43%**
	LBDI	1.26	266	AT8	44.2	48.1	**45.9**	2.9	7.3	**45%**
	EGRB	1.02	216	AT8	44.2	48.7	**46.2**	3.2	8.7	**45%**
	2020 Diesel	1.98	349	AT8	46.4	54.0	**49.6**	3.0	9.0	**43%**
Truck	STDI	1.44	303	AT8	29.4	32.1	**30.6**	3.1	8.6	**39%**
	LBDI	1.89	399	AT8	30.2	32.9	**31.3**	2.8	7.0	**41%**
	EGRB	1.44	305	AT8	30.5	33.6	**31.8**	3.1	8.6	**42%**
	2020 Diesel	3.20	518	AT8	32.8	38.8	**35.3**	3.0	8.6	**41%**
HD Truck	STDI	2.21	466	AT8	20.0	22.2	**20.9**	3.0	8.4	**39%**
	LBDI	2.24	473	AT8	20.5	22.6	**21.4**	3.0	8.4	**41%**
	EGRB	2.19	463	AT8	20.9	23.1	**21.8**	3.0	8.4	**42%**
	2020 Diesel	4.45	603	AT8	25.3	30.1	**27.3**	3.2	10.3	**48%**

Table 3-18: Equivalent performance results for P2 hybrids (with 20% mass, 20% aerodynamic drag and 10% rolling resistance reductions)

Vehicle Class	Engine Type	Displ. L	Torque Nm	EM size kW	Batt size kWh	Trans Type	FTP mpg	HW mpg	Comb mpg	0-30mph s	0-60mph s	% GHG Reduction
Small Car	STDI	0.68	143	11	0.70	DCT6	85.8	72.2	**79.1**	3.7	7.9	**45%**
	LBDI	0.68	144	11	0.70	DCT6	87.6	73.1	**80.4**	3.7	7.9	**46%**
	EGRB	0.68	143	11	0.70	DCT6	89.5	75.4	**82.5**	3.7	8.0	**47%**
	ATKCS	1.60	133	11	0.70	DCT6	89.4	74.9	**82.2**	3.8	8.9	**47%**
	ATKDVA	1.52	127	11	0.70	DCT6	93.9	76.9	**85.4**	3.8	9.0	**49%**
Std Car	STDI	0.90	191	18	1.00	DCT8	78.1	71.1	**74.8**	3.2	7.2	**53%**
	LBDI	0.91	194	18	1.00	DCT8	79.7	72.2	**76.2**	3.3	7.2	**54%**
	EGRB	0.92	194	18	1.00	DCT8	81.4	74.2	**78.0**	3.2	7.1	**55%**
	ATKCS	2.36	197	18	1.00	DCT8	82.2	73.8	**78.2**	3.1	7.5	**55%**
	ATKDVA	2.03	169	18	1.00	DCT8	83.5	76.2	**80.0**	3.3	8.3	**56%**
Large Car	STDI	1.21	254	22	1.10	DCT8	63.2	57.3	**60.4**	3.1	6.6	**55%**
	LBDI	1.25	263	21	1.10	DCT8	64.9	58.5	**61.9**	3.1	6.5	**56%**
	EGRB	1.25	263	21	1.10	DCT8	65.7	59.8	**62.9**	3.1	6.6	**56%**
	ATKCS	3.52	293	21	1.10	DCT8	61.1	57.0	**59.2**	3.0	6.7	**54%**
	ATKDVA	3.29	274	21	1.10	DCT8	63.9	59.3	**61.7**	3.0	6.8	**56%**
Small MPV	STDI	1.25	265	21	1.10	DCT8	63.9	53.4	**58.7**	3.5	7.7	**48%**
	LBDI	1.22	257	22	1.10	DCT8	65.2	53.9	**59.5**	3.5	7.7	**49%**
	EGRB	1.24	262	21	1.10	DCT8	66.5	55.7	**61.1**	3.5	7.8	**50%**
	ATKCS	3.71	309	21	1.10	DCT8	65.0	55.1	**60.1**	3.4	8.2	**49%**
	ATKDVA	3.44	287	21	1.10	DCT8	67.5	56.7	**62.1**	3.6	8.7	**51%**
Large MPV	STDI	1.01	213	28	1.15	DCT8	59.5	50.2	**54.9**	3.2	7.4	**54%**
	LBDI	1.04	219	28	1.15	DCT8	61.0	50.9	**56.0**	3.2	7.3	**55%**
	EGRB	1.02	215	26	1.15	DCT8	60.6	51.6	**56.2**	3.2	7.3	**55%**
	ATKCS	2.91	243	21	1.15	DCT8	58.9	51.1	**55.1**	3.2	7.5	**54%**
	ATKDVA	2.84	237	22	1.15	DCT8	60.1	52.4	**56.3**	3.2	7.7	**55%**
Truck	STDI	1.57	330	41	1.50	DCT8	39.4	34.4	**37.0**	3.2	7.0	**50%**
	LBDI	1.60	337	38	1.50	DCT8	40.3	35.0	**37.7**	3.3	7.0	**51%**
	EGRB	1.58	334	40	1.50	DCT8	41.0	36.0	**38.6**	3.2	7.0	**52%**
	ATKCS	4.16	347	38	1.50	DCT8	39.9	34.9	**37.5**	3.0	7.1	**50%**
	ATKDVA	4.15	346	39	1.50	DCT8	41.4	35.9	**38.7**	3.0	7.2	**52%**

3.3.1.2.22 Validation of vehicle simulation results

Ricardo described the process used to validate the baseline vehicles in its report1. Ideally it would be desirable to validate the simulation results with actual vehicle certification test data. However, due to the nature and intended time frame (10+ years into the future) of the technologies modeled within the vehicle classes, it is difficult to find many real-world examples of specific technologies at the level of development reflected within the latest simulation models. Furthermore, there are no current vehicles in production that contain all (or even a majority) of the multiple advanced technologies embedded within the models so it is difficult to make meaningful direct comparisons between actual vehicles and model results. Finally, there is no direct way to disaggregate the various advanced technologies and isolate only the relevant pieces for evaluation (e.g., an advanced turbocharged engine at an interim BMEP level with a baseline-level transmission without stop-start): the lumped parameter model was developed for this very analytical capability. A full description of the lumped parameter model (including example comparisons of existing vehicle models to lumped parameter estimates) is provided in 3.3.2.

3.3.1.2.23 The "efficient frontier" capability in Complex Systems tool

A powerful feature of the Complex Systems tool is the "efficient frontier" function, which provides a graphical representation of the RSM data for the vehicle configuration of interest. The user can identify the combination of various attributes (engine displacement, final drive ratio, motor size, etc) that project the best model effectiveness. Figure 3-8 below is an example of the efficient frontier for a Standard Car with a cooled EGR turbocharged engine and a dry clutch DCT. The light red line along the top of the data set represents the best fuel economy at each 0-60 mph acceleration time within the desired window. The solid dark blue points represent the combinations that achieve both the desired 0-60 and 0-30 mph criteria for equivalent performance. In this way, it is easy to quantify the best effectiveness for a given technology package.

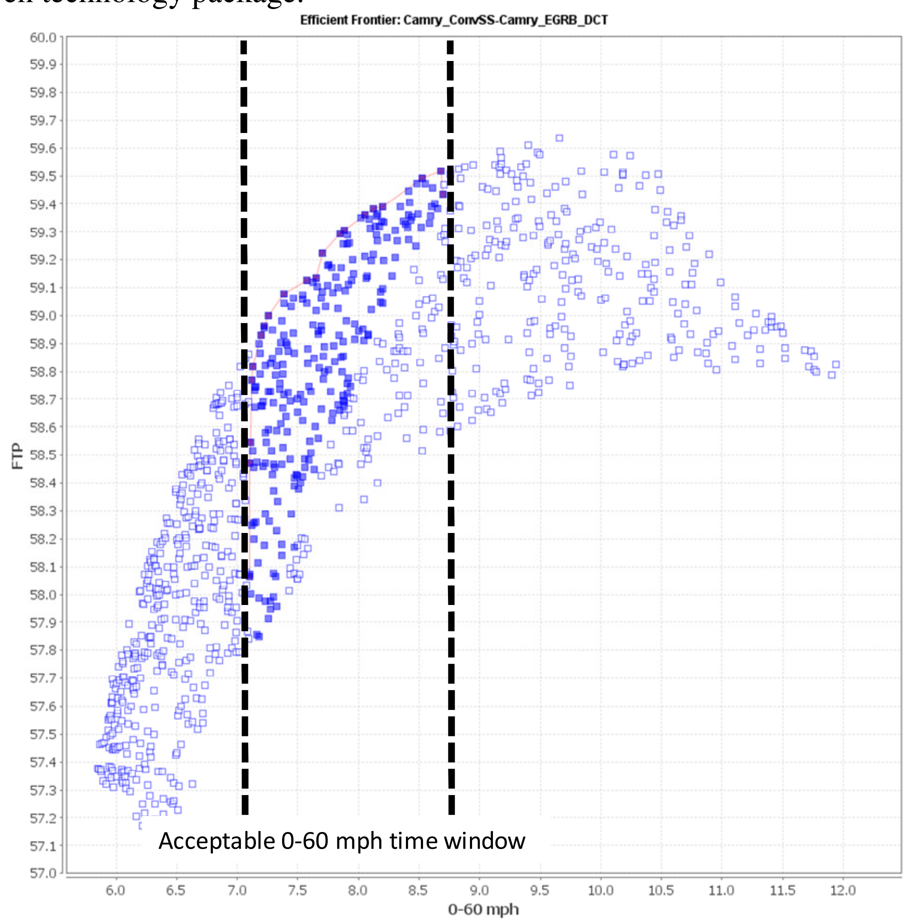


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Figure 3-8: "Efficient Frontier" function in complex systems tool

3.3.1.2.24 Significance of the Complex Systems tool

The complex systems tool was used not only to identify the optimal combination of input variables for each vehicle architecture, but also to analyze trends in the input variables for quality assurance (i.e., to make sure the response surface models made engineering sense), and to establish numerical relationships between these variables for the lumped parameter model calibration. Shown below are a few examples of the types of inquiries made via the complex systems tool:

3.3.1.2.24.1 Effects of motor size (HEVs)

EPA reviewed the effects of motor size on hybrids. As motor size is increased, there is more opportunity to recapture energy during braking (because more powerful motors can recover all of the energy in more severe braking events). However, oversized motors also experience reduced efficiency as they operate in a less efficient operating region. This is shown in Figure 3-9 below, which shows a sweep of motor size vs. fuel economy for both the FTP/HWFE combined and also the high speed/load US06 cycle. Note that the optimum motor size increases with respect to the US06 cycle due to more severe braking and acceleration rates.

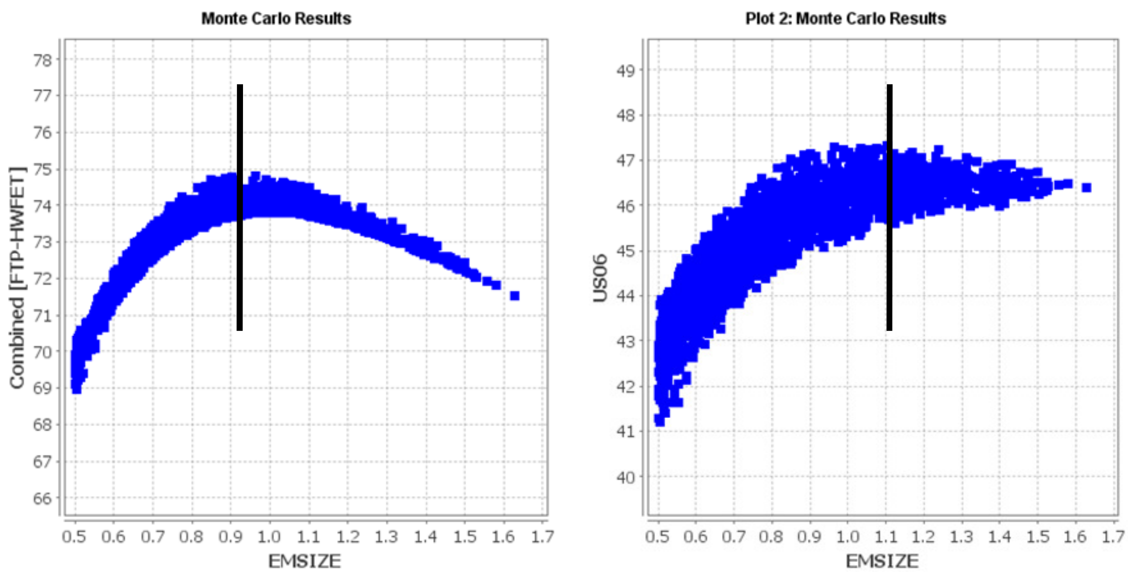

Figure 3-9: Electric motor sweeps for Standard Car class, P2 hybrid with stoichiometric GDI engine (left = FTP/HWFE test; right = US06 test)

3.3.1.2.24.2 Effects of engine displacement

EPA reviewed the effects of engine displacement at equivalent performance to determine if there would be an "optimal" range of downsizing for best effectiveness. Surprisingly, there was little benefit beyond downsizing the engine past a minimal point. Shown in Figure 3-10 is an example complex systems tool graph with fuel economy plotted against engine displacement multiplier (compared to the "nominal" engine displacement) for the Truck class for three gasoline turbocharged engine packages and one diesel engine package (note all packages included 20% weight reduction, 20% aerodynamic drag reduction, and 10% rolling resistance reduction):

- The diesel engine result shows that the nominal engine in this case was originally oversized because it was scaled on engine power not more accurately on engine torque and continued displacement reduction would improve fuel economy. For this package, the displacement for optimal fuel economy is smaller than 50% of the nominal value; however, when considering equivalent vehicle performance, the minimum diesel displacement increases to roughly 70% of the nominal value.

- In contrast, the gasoline turbo engine results shown reflect a relative insensitivity of displacement to fuel economy for these advanced vehicles.

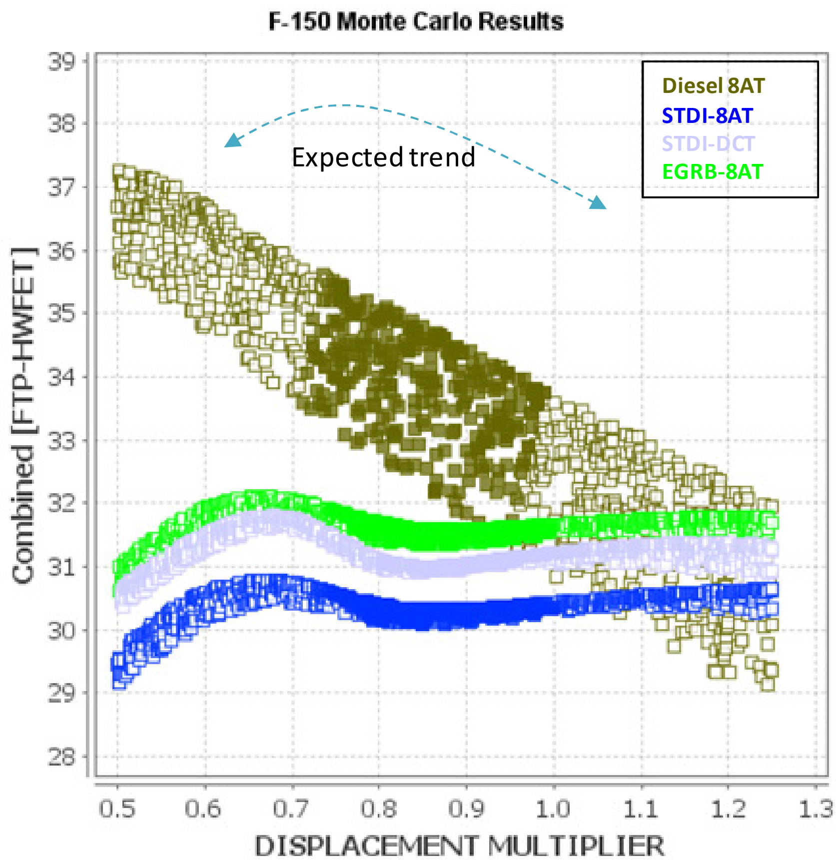

Figure 3-10: Example displacement sweep for Truck class in complex systems tool

Figure 3-10 shows that as modeled, the swept displacement range is not large enough for the advanced gasoline turbocharged engines. The displacement multiplier for these engines must be greater than 1.3x the nominal displacement before the fuel economy would degrade substantially. As the displacement drops below about 65% of the nominal (already downsized) value, the efficiency decreases, as the engine load must be much higher to provide the same required power. Regardless, the total fuel efficiency decrease from optimal is rather small compared to today's engines. A 27-bar cooled EGR turbocharged GDI engine map for a large car[z] was reverse-engineered from the Ricardo 10 Hz output data, and is provided in Figure 3-11. The efficiency of this family of engines is very robust to changes in engine displacement because the highlighted BSFC region of interest (the second one out from the minimum BSFC "island") spans a large speed and load range. As a result, significant changes in displacement do not greatly reduce fuel efficiency. As displacement increases, the average operating points for the engine over a given test cycle will trend towards the lower left (lower speed, lower load[aa]) portion of the map. In this case the points on the plot exist within the same BSFC contour, so there is little degradation in engine efficiency with increasing displacement (and drivetrain efficiency may improve at higher gears, potentially resulting in a fuel economy increase). Were the displacement to be increased much further, the operating region would cross the contour and fuel efficiency would begin to drop much more dramatically.

[z] The 27 bar, cooled EGR turbocharged engine maps are similar for all classes as they originated from a common reference map and scaled according to engine displacement, as described in Section 6.3 of the 2011 Ricardo report.

[aa] Load decreases as it is reflective of a % of the maximum achievable torque and torque is increasing with increased displacement. Speed decreases because of the greater torque available combined with the shift optimizer algorithm (allowing for a greater propensity to operate in higher gears).

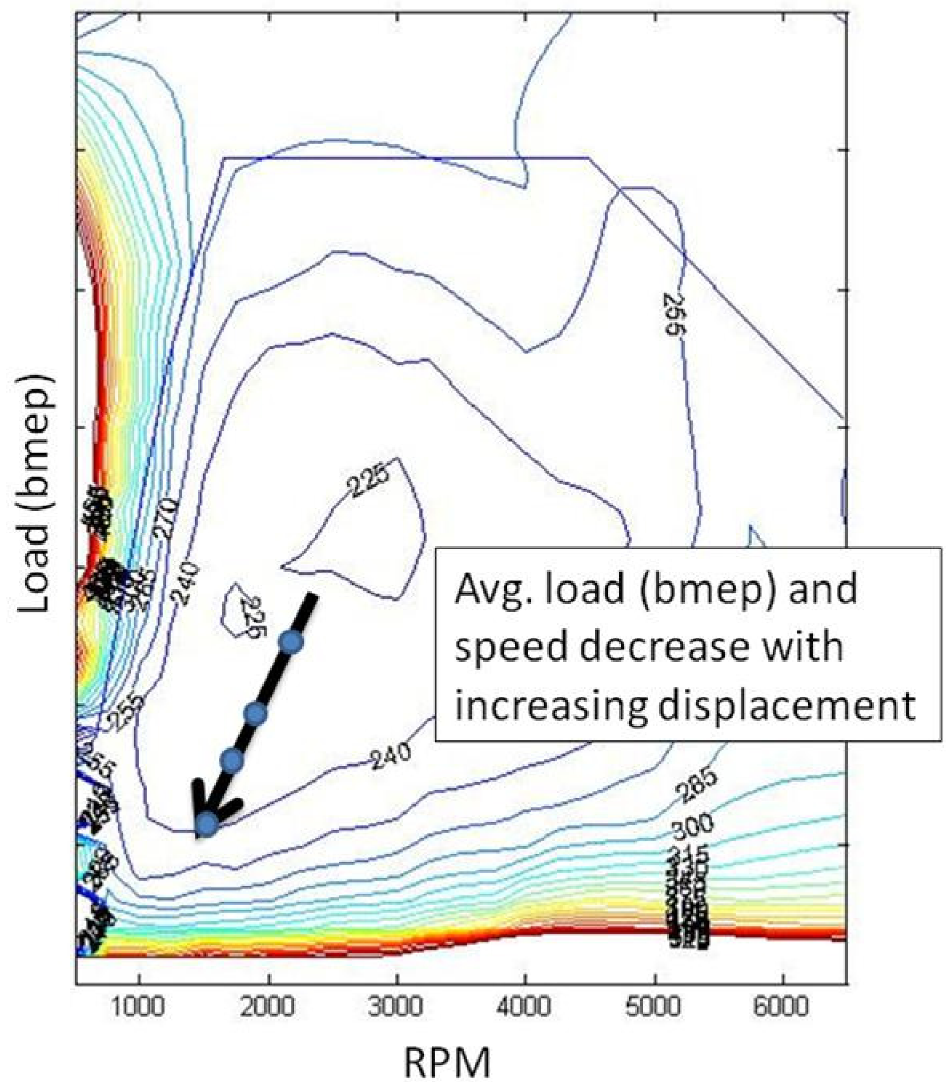

Figure 3-11: Advanced engine BSFC map (27-bar cooled EGR turbocharged GDI engine for large car)

3.3.1.2.25 Effects of mass reduction

With the complex systems tool EPA isolated the effectiveness of mass reduction on advanced vehicle technology packages. Figure 3-12 below shows a mass reduction sweep plot of the Large MPV class for a conventional STDI and P2 hybrid vehicle with an Atkinson engine.

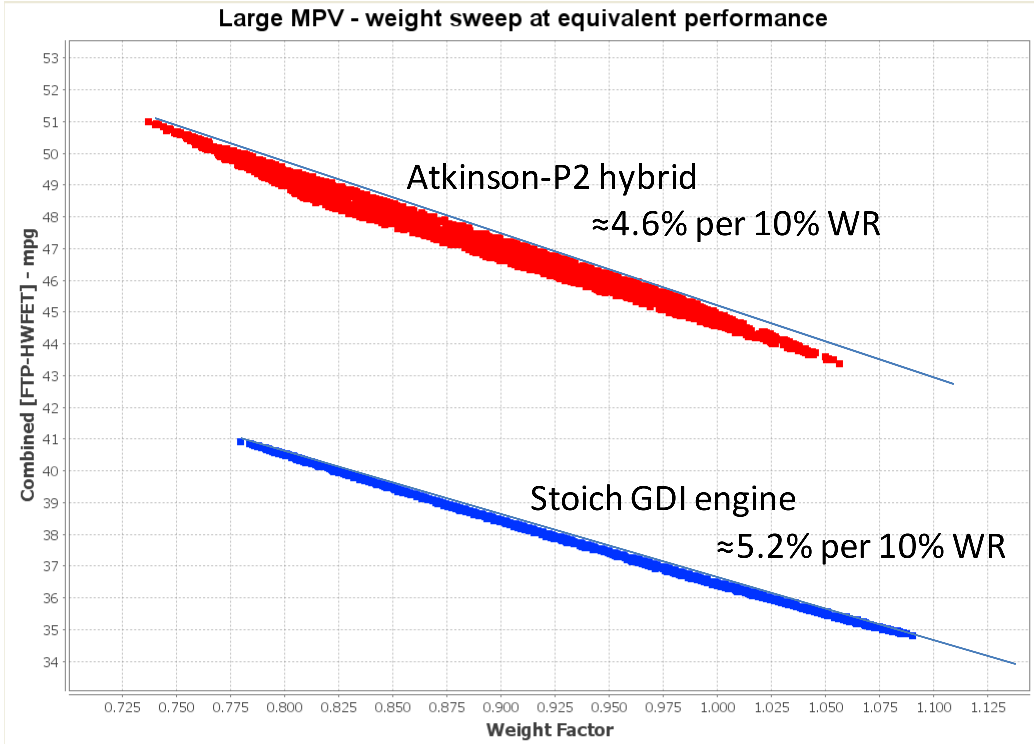

Figure 3-12: Mass reduction sweep for Large MPV class at baseline equivalent performance. Engine displacement and motor size (hybrids) held constant.

The mass reduction effectiveness, originally estimated at roughly 6% GHG reduction for a 10% reduction in mass, has been revised to reflect data such as that shown above. Isolated from benefits due to engine downsizing opportunities, the effectiveness of weight reduction for the non-hybrid packages is on the order of 5% per 10% weight reduction, while mass reduction for the P2 hybrid (or any hybrid) is reduced, on the order of 4.5% per 10% reduction due to the synergies with brake energy recovery (less braking energy is recoverable because the vehicle weighs less). The lumped parameter tool was also revised to incorporate the synergies of weight reduction and hybrids.

3.3.1.2.26 Vehicle simulation report peer review process

As previously discussed, vehicle simulation modeling is a very detailed, mathematically intensive approach which relies heavily on numerical engineering inputs. These inputs (e.g., engine maps, transmission efficiency, control logic, etc.) are the heart of the model and are derived directly from proprietary engineering knowledge of components and subsystems. To simulate advanced engine and vehicle concepts, state-of-the-art knowledge must be applied and converted into modeling inputs. Public domain information is rarely at the forefront of technology, and of little use in modeling vehicles in the MYs 2017-2025 time frame.

Engineering details on advanced vehicle technologies are closely guarded in industry, and engineering services companies which develop and generate this confidential information rely on it to remain competitive in the marketplace. Therefore, it is difficult, if not impossible, to be completely transparent with an advanced vehicle simulation model and make all of the inputs available for public review. EPA commissioned an external peer review of the 2011 Ricardo simulation project and report. The peer reviewers selected were highly respected members of academia and industry, all with substantial backgrounds in automotive technology. The list of peer reviewers and their credentials is provided in the associated peer review report[35].

EPA charged the peer reviewers to thoroughly evaluate the body of work with respect to the following topics:

- Adequacy of the numerical inputs (engine technology selection, battery inputs, accessory load assumptions, etc.) and highlight any caveats or limitations that would affect the final results.
- Validity and applicability of the simulation methodology, and if it adequately addresses synergies
- The results, and their validity and applicability to the light-duty vehicle fleet in the 2020-2025 timeframe.
- Completeness of the report (does it offer enough detail of the modeling process)
- The overall adequacy of the report for predicting the effectiveness of these technologies, and suggest recommendations for improvement

The first round of comments was reflective of the reviewer's lack of access to model inputs. Because the confidential inputs were initially withheld (for reasons described above), "lack of transparency" was a consistent theme amongst the reviewers, so much that they expressed frustration with their ability to evaluate the model methodology and the quality of the inputs. Additionally, due to the lack of access to Ricardo proprietary input data the peer reviewers expressed concern that they could not adequately judge the validity or accuracy of the input information or the simulation results. EPA worked with Ricardo to provide the peer reviewers with access to all of the detailed confidential modeling inputs under non-disclosure agreements. With this necessary information, 3 of the 5 peer reviewers submitted a second round of comments which were generally more specific. In turn, Ricardo modified the report to address some of the comments, and they developed a response to comments document which covered the comments from the peer review. One common theme called for increased detail in how the inputs were generated. To address these requests, Ricardo provided the detailed case studies that were used in the development of the engine maps for the cooled EGR boosted engines and the Atkinson engines for hybrids. Ricardo also elaborated on the hybrid control strategy, complete with state flow diagrams of operating modes, as well as a discussion of how hybrid control strategy was optimized. Additional transmission input details were provided, including an overview of the development of advanced gear efficiencies and how the optimized shift strategy was applied.

The docket to this final rule contains Ricardo's response to comment document (which includes the first version of the Ricardo report that was peer reviewed and both rounds of peer review comments), and Ricardo's final report.[36,37] The agencies sought comment on the all of these references and on the responsiveness of the final report to the peer review comments.

3.3.1.3 Argonne National Laboratory Simulation Study

As discussed in the proposal, the U.S. D.O.T. Volpe Center has entered into a contract with Argonne National Laboratory (ANL) to provide full vehicle simulation modeling support for this MYs 2017-2025 rulemaking. While modeling was not complete in time for use in the NPRM, the ANL results were available for the final rule and were used to define the effectiveness of mild hybrids for both agencies, and NHTSA used the results to update the effectiveness of advanced transmission technologies coupled with naturally-aspirated engines for the CAFE analysis, as discussed above and more fully in NHTSA's RIA. This simulation modeling was accomplished using ANL's full vehicle simulation tool called "Autonomie," which is the successor to ANL's Powertrain System Analysis Toolkit (PSAT) simulation tool, and that includes sophisticated models for advanced vehicle technologies. The ANL simulation modeling process and results are documented in multiple reports that can be found in NHTSA's docket[38].

3.3.2 Lumped parameter Modeling

3.3.2.1 Overview of the lumped parameter model

As a more practical alternative to full vehicle simulation, EPA developed a "lumped parameter model" that estimates the effectiveness of various technology combinations or "packages," in a manner that accounts for synergies between technologies. In the analysis supporting the MYs 2012-2016 light duty vehicle GHG and CAFE rule, EPA built over 140 packages for use in its OMEGA model, which spanned 19 vehicle classes and over 1100 vehicle models. Vehicle simulation modeling performed for EPA by Ricardo, PLC, was used to calibrate the lumped parameter model. Although DOT's analysis supporting the MYs 2012-2016 CAFE rule applied technologies incrementally, rather than specifying packages in advance, DOT calibrated CAFE model inputs, using EPA's lumped parameter model, to harmonize as fully as practical with estimates produced by EPA's lumped parameter model.

To support this rulemaking, EPA has updated its lumped parameter model and calibrated it with updated vehicle simulation work performed for EPA by Ricardo, PLC. As in the MYs 2012-2016 rulemaking, DOT has calibrated inputs, including synergy factors, to the CAFE model to as fully as practical align with estimates produced by EPA's lumped parameter model.

Both agencies have continued to conduct and sponsor vehicle simulation efforts to improve inputs to the agencies' respective modeling systems. For the final rule, simulation results for the mild hybrid technology have been incorporated into the modeling systems for both agencies. Also, NHTSA updated the incremental effectiveness of advanced transmissions as applied to naturally-aspirated engines, a change which was only implemented in the CAFE model.

The basis for EPA's lumped parameter analysis is a first-principles energy balance that estimates the manner in which the chemical energy of the fuel is converted into various forms of thermal and mechanical energy on the vehicle. The analysis accounts for the dissipation of energy into the different categories of energy losses, including each of the following:

- Second law losses (thermodynamic losses inherent in the combustion of fuel),
- Heat lost from the combustion process to the exhaust and coolant,
- Pumping losses, i.e., work performed by the engine during the intake and exhaust strokes,
- Friction losses in the engine,
- Transmission losses, associated with friction and other parasitic losses of the gearbox, torque converter (when applicable) and driveline
- Accessory losses, related directly to the parasitics associated with the engine accessories,
- Vehicle road load (tire and aerodynamic) losses;
- Inertial losses (energy dissipated as heat in the brakes)

The remaining energy is available to propel the vehicle. It is assumed that the baseline vehicle has a fixed percentage of fuel lost to each category. Each technology is grouped into the major types of engine loss categories it reduces. In this way, interactions between multiple technologies that are applied to the vehicle may be determined. When a technology is applied, the lumped parameter model estimates its effects by modifying the appropriate loss categories by a given percentage. Then, each subsequent technology that reduces the losses in an already improved category has less of a potential impact than it would if applied on its own.

Using a lumped parameter approach for calculating package effectiveness provides necessary grounding to physical principles. Due to the mathematical structure of the model, it naturally limits the maximum effectiveness achievable for a family of similar technologies[bb]. This can prove useful when computer-simulated packages are compared to a "theoretical limit" as a plausibility check. Additionally, the reduction of certain energy loss categories directly impacts the effects on others. For example, as mass is reduced the benefits of brake energy recovery decreases because there is not as much inertia energy to recapture.

Figure 3-13 is an example spreadsheet used by EPA to estimate the package effectiveness and the synergistic impacts of a technology package for a standard-size car.

[bb] For example, if only 4% of fuel energy is lost (in a baseline engine) to pumping work, leveraging multiple technologies to theoretically eliminate all pumping losses would yield an aggregate reduction of no more than 15% in fuel consumption.

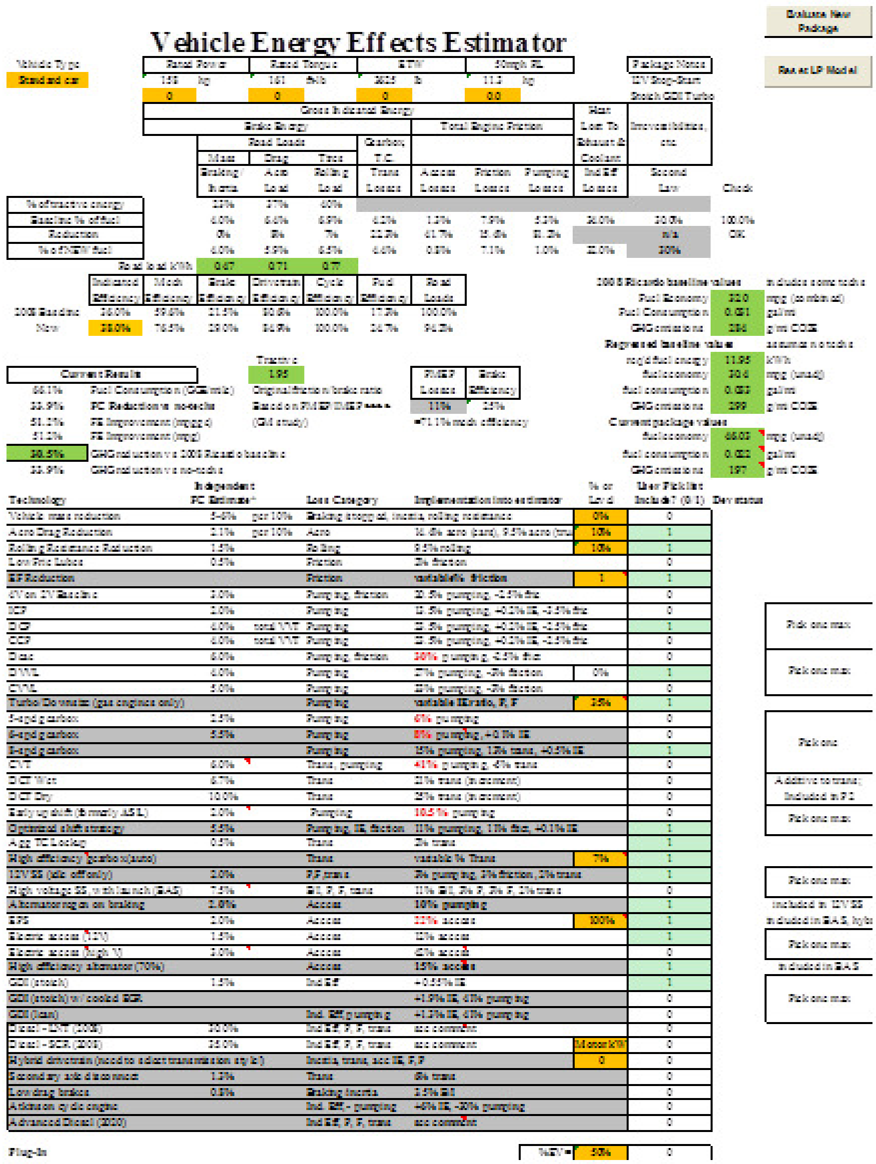

Figure 3-13 Sample lumped parameter model spreadsheet

The LP model has been updated from the MYs 2012-2016 final rule to support the MYs 2017-2025 final standards. Changes were made to include new technologies for 2017 and beyond, improve fidelity for baseline attributes and technologies, and better represent hybrids based on more comprehensive vehicle simulation modeling. EPA RIA Chapter 1 provides details of the methodology used to update and refine the model.

3.3.2.2 Calibration of Lumped Parameter model to vehicle simulation data

The lumped parameter model includes a majority of the new technologies being considered as part of this proposed rulemaking. The results from the Ricardo vehicle simulation project (See section 3.3.1 for additional information) were used to successfully calibrate the predictive accuracy and the synergy calculations that occur within the lumped parameter model. When the vehicle packages Ricardo modeled are estimated in the lumped parameter model, the results are comparable. All of the baselines for each vehicle class, as predicted by the lumped parameter model, fall within 3% of the Ricardo-modeled baseline results. With a few exceptions (discussed in Chapter 1 of EPA's RIA the lumped parameter results for the 2020-2025 "nominal" technology packages are within 5% of the vehicle simulation results. Shown below in Figure 3-14 through Figure 3-19 are Ricardo's vehicle simulation package results (for conventional stop-start and P2 hybrid packages[cc]) compared to the lumped parameter estimates.

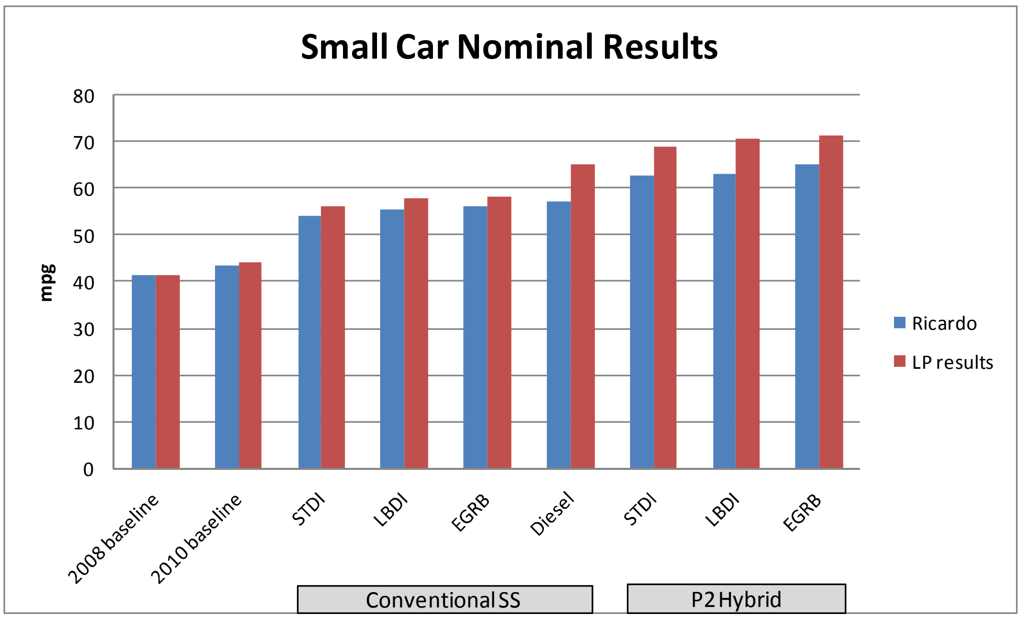

Figure 3-14: Comparison of LP to simulation results for Small Car class

[cc] Refer to 3.3.1for definitions of the baselines, "conventional stop-start" and "P2 hybrid" vehicle architectures.

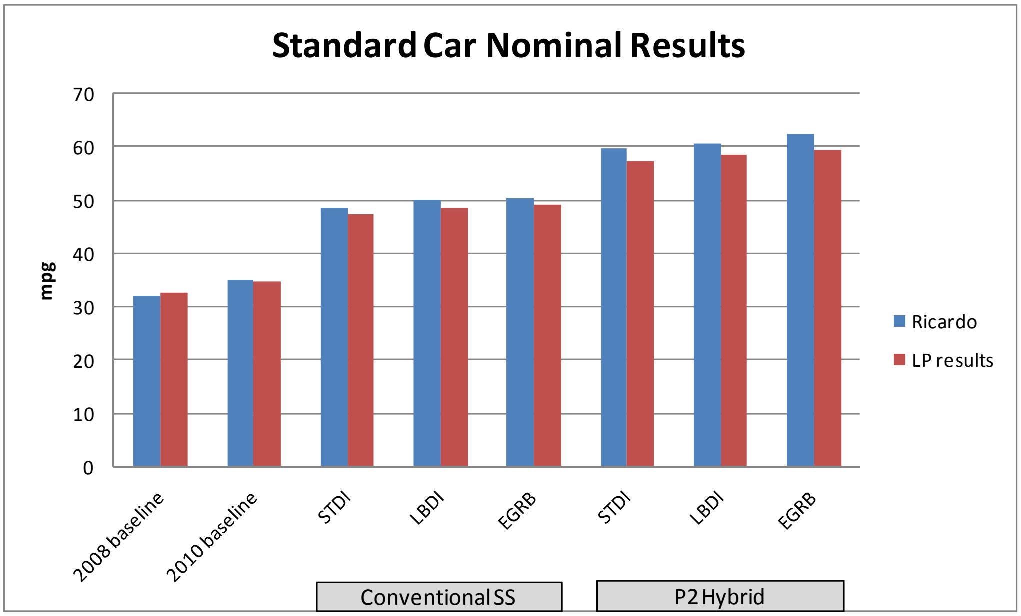

Figure 3-15: Comparison of LP to simulation results for Standard Car class

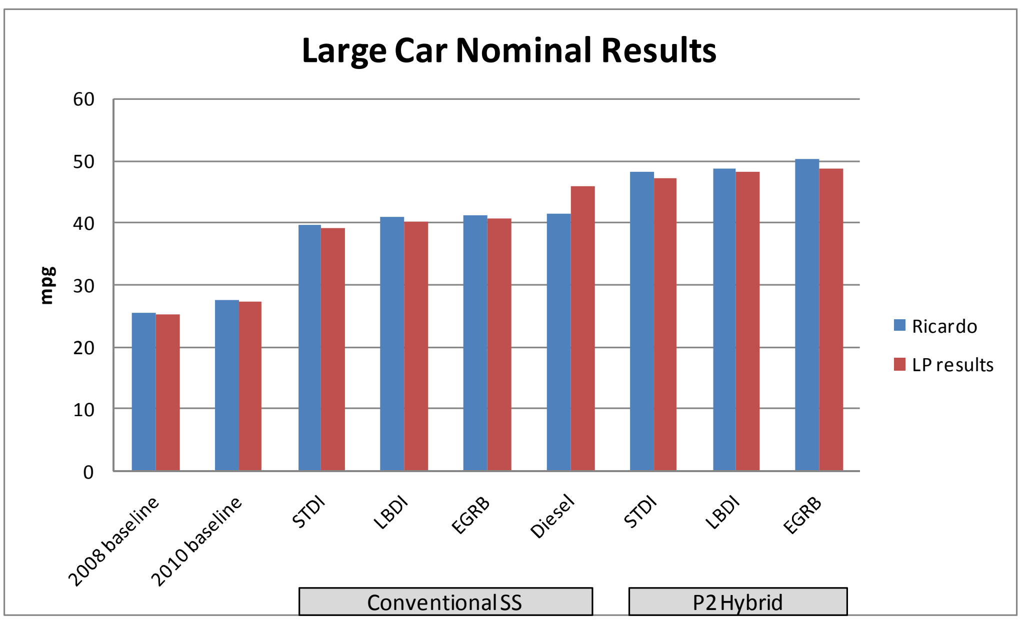

Figure 3-16: Comparison of LP to simulation results for Large Car class

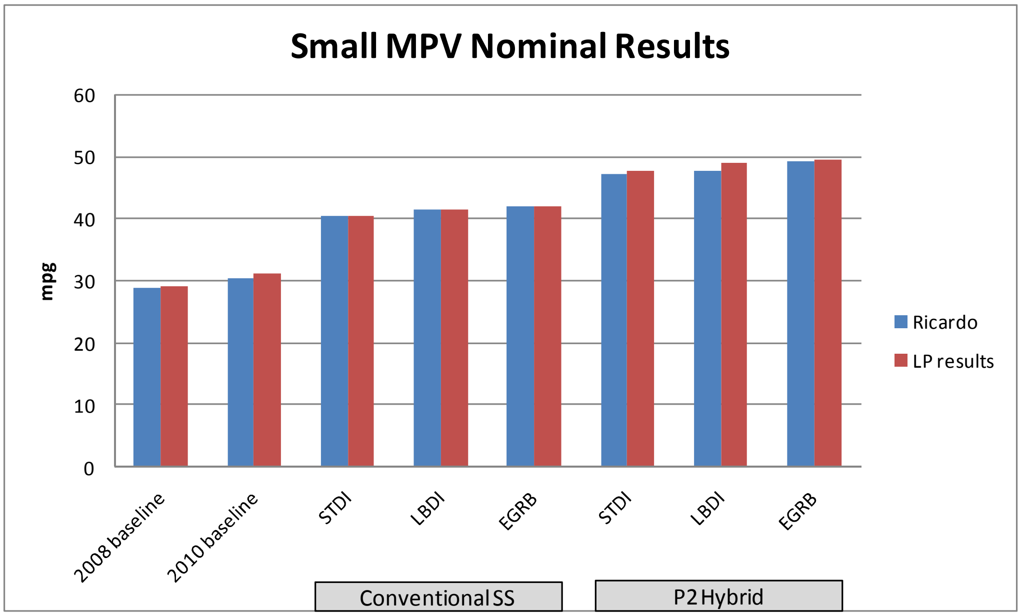

Figure 3-17: Comparison of LP to simulation results for Small MPV class

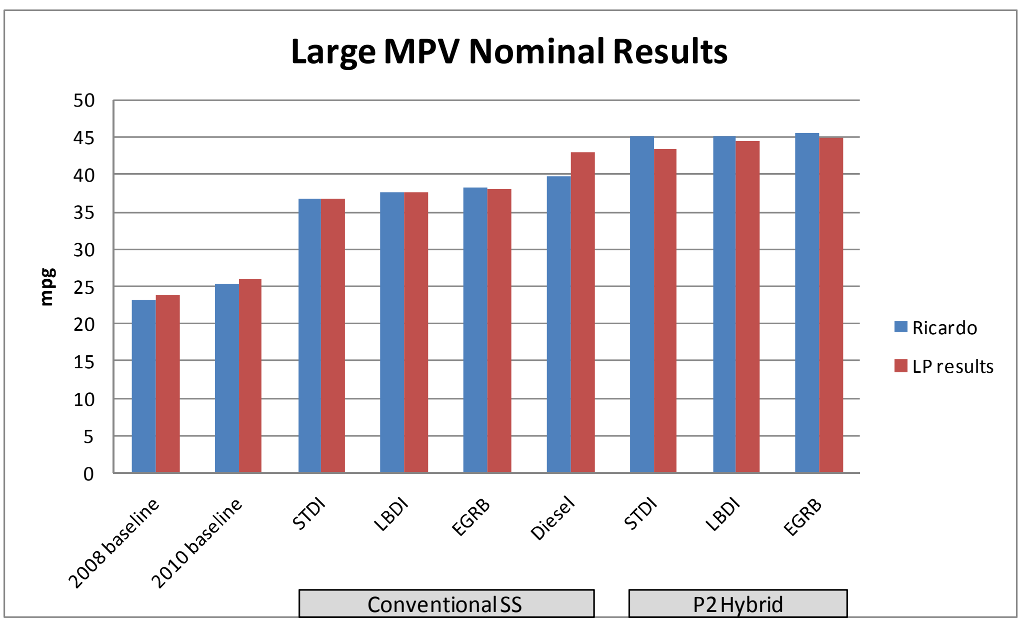

Figure 3-18: Comparison of LP to simulation results for Large MPV class

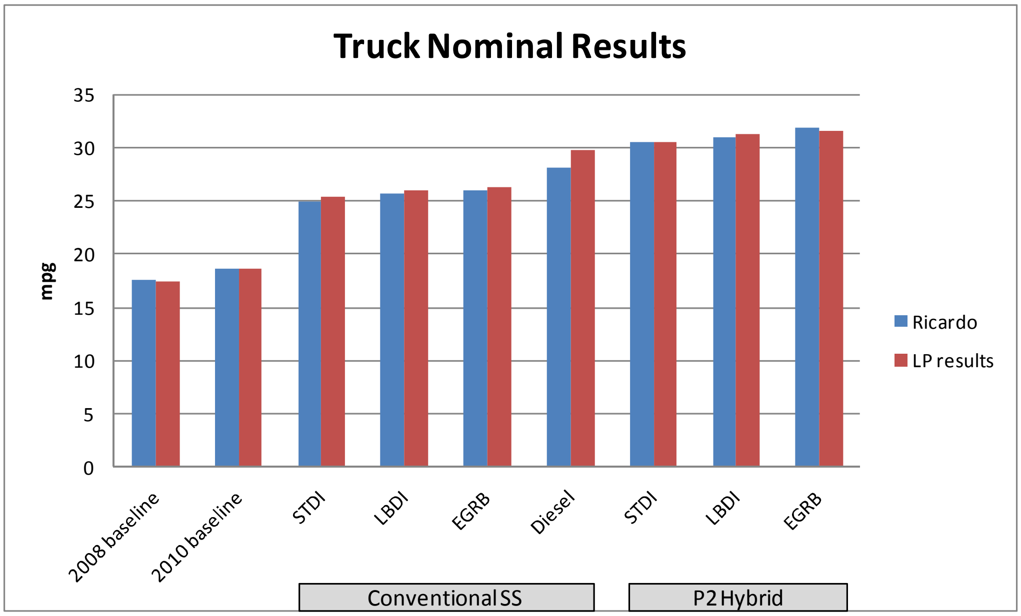

Figure 3-19: Comparison of LP to simulation results for Truck class

The recent ANL modeling results for mild hybrids largely confirmed the effectiveness as originally predicted by the lumped parameter model, with minor differences for small cars and large trucks. A comparison of the ANL results to the original lumped parameter results (for comparable vehicle classes when modeled with a nominal 15 kW motor size) is shown below in Table 3-19 and Table 3-20.

Table 3-19 ANL Effectiveness for Mild Hybrid

	Compact	Midsize	Small SUV	Midsize SUV	Pickup
FC reduction	11.6%	11.6%	10.2%	10.5%	8.5%

Table 3-20 Lumped Parameter Model Effectiveness for Mild Hybrid

	Small Car	Std Car	Small MPV	Large MPV	Truck
FC reduction	14.1%	11.8%	10.1%	10.1%	6.9%

The underlying structure of the lumped parameter model was not changed to accommodate this new information; instead, the nominal 15 kW motor sizes for small cars and pickup truck mild hybrids were adjusted (to 10 kW and 18 kW, respectively) to reflect the updated effectiveness results provided by the ANL simulation work.

3.3.2.3 Comparison of results to real-world examples

To validate the lumped parameter model, representations of actual late-model production vehicles exhibiting advanced technologies were created. Shown in Table 3-21 are a set of select vehicle models containing a diverse array of technologies: included are the pertinent technologies and vehicle specifications, along with actual vehicle certification fuel economy test data compared to the lumped parameter fuel economy estimates. For the vehicles and technologies shown, the predicted fuel economy is within about 3% of the actual data.

Table 3-21: Production vehicle certification data compared to lumped parameter predictions

Vehicle	2011 Chevy Cruze ECO	2011 Sonata Hybrid	2011 Escape Hybrid	2011 F-150 EcoBoost
Vehicle Class	Small Car	Standard Car	Small MPV	Truck
Engine	1.4L I4 Turbo GDI	2.4L I4 Atkinson	2.5L I4 Atkinson	3.5L V6 Turbo GDI
Transmission	6 speed auto	6 speed auto	CVT	6 speed auto
HEV motor (kW)	n/a	30	67	n/a
ETW (lbs)	3375	3750	4000	6000
City/HW FE (mpg)	40.3	52.2	43.9	22.6
LP estimate (mpg)	40.2	51.7	44.0	21.9
Key technologies applied in LP model	GDI (stoich) Turbo (30% downsize) Ultra low R tires Active grill shutters	P2 hybrid Aero improvements	Powersplit hybrid	GDI (stoich) Turbo (37% downsize)

3.4 What cost and effectiveness estimates have the agencies used for each technology?

As discussed in the previous sections, many the effectiveness estimates for this final rule, consistent with the proposal, including the estimates for the technologies carried over from the MYs 2012-2016 final rule, are derived from the 2011 Ricardo study and corresponding updated version of the lumped-parameter model. It is important to note that the agencies used the average of the range presented when referencing the effectiveness estimates from the MYs 2012-2016 final rule. If, for example, the effectiveness range for technology X was determined to be 1 to 2 percent, the agencies used a value of 1.5 percent in their respective analyses. However, the effectiveness ranges that are presented for the MYs 2017-2025 analysis, as informed by the Ricardo 2011 study, define the range of estimates used by the agencies for the different vehicle types. Again using technology X as an example, if the range is now defined as 2.0 to 2.5 percent then for small passenger cars (subcompact or compact) the estimated effectiveness might be 2.0 percent but for large cars an estimate of 2.5 percent might be used.

As noted in section 3.1.3, the effects of learning on individual technology costs can be seen in the cost tables presented throughout this section 3.3. For each technology, we show direct manufacturing costs for the years 2017 through 2025. The changes shown in the direct manufacturing costs from year-to-year reflect the cost changes due to learning effects.

3.4.1 Engine technologies

As indicated in the cost tables that found in this section, the agencies updated the costing approach for some technologies in an effort to provide better granularity in our estimates. This is reflected in Table 3-23, among others, listing costs for technologies by engine configuration—in-line or "I" versus "V"—and/or by number of cylinders. In the MYs 2012-2016 final rule, we showed costs for identified vehicle classes such as small car, large car, large truck, etc. The identified challenges inherent with that approach are that different vehicle classes can have many different sized engines. This condition may become more prominent going forward as more turbocharged and downsized engines enter the fleet. For example, the agencies project that many vehicles in the large car class, have large displacement V8 or V6 engines would move to highly turbocharged I4 engines under the final rule, consistent with the proposal. As such, we would not want to estimate the costs of engine friction reduction for large cars—which have always and continue to be based on the number of cylinders—by assuming that all large cars have V8 or V6 engines.

3.4.1.1 Low Friction Lubricants

A basic method of reducing fuel consumption in gasoline engines is using of lower viscosity engine lubricants. Advanced multi-viscosity engine oils are available today which yield improved performance in a wider temperature band and with better lubricating properties. These advances are accomplished by changes to the oil base stock (e.g., switching engine lubricants from a Group I base oils to lower-friction, lower viscosity Group III synthetic) and through changes to lubricant additive packages (e.g., friction modifiers and viscosity improvers). The use of 5W-30 motor oil is now widespread and auto manufacturers are introducing the use of lower viscosity oils, such as 5W-20 and 0W-20, to improve cold-flow properties and reduce cold start friction. However, in some cases, changes to the crankshaft, connecting rod and main crankshaft bearing designs and/or materials along with the mechanical tolerances of engine components may be required. In all cases, durability testing would be required to ensure that durability is not compromised. Shifting to lower viscosity and lower friction lubricants can also improve the management of valvetrain technologies such as cylinder deactivation or variable valve timing, which rely on a minimum oil temperature (viscosity) for operation.

Several manufacturers have previously commented confidentially that low friction lubricants could have an effectiveness value between 0 to 1 percent. The agencies used the average effectiveness of 0.5 in the MYs 2012-2016 final rule. For purposes of this final rule, consistent with the proposal, the agencies relied on the lumped parameter model and the range for the effectiveness of low friction lubricant is 0.5 to 0.8 percent.

In the MYs 2012-2016 final rule, the 2010 TAR and the MYs 2014-2018 Medium and Heavy Duty GHG and Fuel Efficiency final rule, EPA and NHTSA used a direct manufacturing cost (DMC) of $3 (2007$) and considered that cost to be independent of vehicle class since the engineering work required should apply to any engine size. The agencies continue to believe that this cost is appropriate and, having adjusted for 2010$, the cost remains the same for this analysis. No learning is applied to this technology so the DMC remains $3 (2010$) year-over-year. The agencies have used a low complexity ICM of 1.24 for this technology through 2018 and 1.19 thereafter. The resultant costs are shown in Table 3-22.[dd] Note that low friction lubes are expected to exceed 85 percent penetration by the 2017 MY.

Table 3-22 Costs for Engine Modifications to Accommodate Low Friction Lubes (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	$3	$3	$3	$3	$3	$3	$3	$3	$3
IC	All	$1	$1	$1	$1	$1	$1	$1	$1	$1
TC	All	$4	$4	$4	$4	$4	$4	$4	$4	$4

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

3.4.1.2 Engine Friction Reduction

In addition to low friction lubricants, manufacturers can also reduce friction and improve fuel consumption by improving the design of engine components and subsystems. Approximately 10 percent of the energy consumed by a vehicle is lost to friction, and just over half is due to frictional losses within the engine.[39] Example improvements include low-tension piston rings, piston skirt design, roller cam followers, improved crankshaft design and bearings, material coatings, material substitution, more optimal thermal management, and piston and cylinder surface treatments. Additionally, as computer-aided modeling software continues to improve, more opportunities for evolutionary friction reductions may become available.

All reciprocating and rotating components in the engine are potential candidates for friction reduction where minute improvements in several components can result in a

[dd] Note that the costs developed for low friction lubes for this analysis reflect the costs associated with any engine changes that would be required as well as any durability testing that may be required.

measurable fuel economy improvement. In the MYs 2012-2016 final rule, the agencies relied on the 2002 NAS, NESCCAF and EEA reports, as well as, confidential manufacturer data that suggested a range of effectiveness for engine friction reduction (EFR1) to be between 1 to 3 percent. Because of the incremental technology application capability of the CAFE model, NHTSA used the narrower range of 1 to 2 percent, which resulted in an average effectiveness of 1.5 percent. Based on the 2011 Ricardo study results, the agencies have revised the effectiveness for engine friction reduction range to 2.0 to 2.7 percent for this analysis.

For this final rule, consistent with the proposal, the agencies added a second level of incremental improvements in engine friction reduction (EFR2) applicable over multiple vehicle redesign cycles. This second level of engine friction reduction forecasts additional improvements to low friction lubricants relative to the low friction lubricant technology discussed above and is considered to be mature only after MY 2017. The effectiveness for this second level, relative to the base engine, is 3.4 to 4.8 percent based on the lumped parameter model. Because of the incremental technology application capability of the CAFE model, NHTSA used the effectiveness range of 0.83 to 1.37 percent incremental to the first level of engine friction reduction and low friction lubricants for a total effectiveness of 2.83 to 4.07 percent.

In the MYs 2012-2016 rule, the 2010 TAR and the MYs 2014-2018 Medium and Heavy Duty GHG and Fuel Efficiency final rule, NHTSA and EPA used a EFR1 cost estimate of $11 (2007$) per cylinder DMC, or $12 (2010$) per cylinder in this analysis. No learning is applied to this technology so the DMC remains $12 (2010$) year-over-year. The agencies have used a low complexity ICM of 1.24 for this technology through 2018 and 1.19 thereafter. The resultant costs are shown in Table 3-23. Note that EFR1 is expected to exceed 85 percent penetration by MY 2017.

Table 3-23 Costs for Engine Friction Reduction – Level 1 –EFR1 (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	I3	$36	$36	$36	$36	$36	$36	$36	$36	$36
DMC	I4	$48	$48	$48	$48	$48	$48	$48	$48	$48
DMC	V6	$71	$71	$71	$71	$71	$71	$71	$71	$71
DMC	V8	$95	$95	$95	$95	$95	$95	$95	$95	$95
IC	I3	$9	$9	$7	$7	$7	$7	$7	$7	$7
IC	I4	$11	$11	$9	$9	$9	$9	$9	$9	$9
IC	V6	$17	$17	$14	$14	$14	$14	$14	$14	$14
IC	V8	$23	$23	$18	$18	$18	$18	$18	$18	$18
TC	I3	$44	$44	$43	$43	$43	$43	$43	$43	$43
TC	I4	$59	$59	$57	$57	$57	$57	$57	$57	$57
TC	V6	$89	$89	$85	$85	$85	$85	$85	$85	$85
TC	V8	$118	$118	$113	$113	$113	$113	$113	$113	$113

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

The agencies have estimated the DMC of the second level of friction reduction and low friction lubricants at double the combined DMCs of EFR1 (double the DMC relative to the baseline). As a result, the costs of EFR2 are as shown in Table 3-24. For EFR2 the agencies have used a low complexity ICM of 1.24 through 2024 and 1.19 thereafter.

Table 3-24 Costs for Engine Friction Reduction – Level 2 – EFR2 (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	I3	$78	$78	$78	$78	$78	$78	$78	$78	$78
DMC	I4	$102	$102	$102	$102	$102	$102	$102	$102	$102
DMC	V6	$149	$149	$149	$149	$149	$149	$149	$149	$149
DMC	V8	$197	$197	$197	$197	$197	$197	$197	$197	$197
IC	I3	$19	$19	$19	$19	$19	$19	$19	$19	$15
IC	I4	$25	$25	$25	$25	$25	$25	$25	$25	$20
IC	V6	$36	$36	$36	$36	$36	$36	$36	$36	$29
IC	V8	$48	$48	$48	$48	$48	$48	$48	$48	$38
TC	I3	$97	$97	$97	$97	$97	$97	$97	$97	$93
TC	I4	$126	$126	$126	$126	$126	$126	$126	$126	$121
TC	V6	$185	$185	$185	$185	$185	$185	$185	$185	$178
TC	V8	$244	$244	$244	$244	$244	$244	$244	$244	$234

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

3.4.1.3 Cylinder Deactivation

In conventional spark-ignition engines, throttling the intake airflow controls engine torque output. At partial loads, efficiency can be improved by using cylinder deactivation instead of throttling. Cylinder deactivation (DEAC) can improve engine efficiency by disabling or deactivating (usually) half of the cylinders when the load is less than half of the engine's total torque capability. Cylinder deactivation is achieved by keeping specific cylinder valves closed and stopping fuel flow to the specified cylinder. As a result, the trapped air within the deactivated cylinders is simply compressed and expanded as an air spring, with reduced friction and heat losses. The active cylinders combust at almost double the load required if all of the cylinders were operating. Overall engine pumping losses are significantly reduced as long as the engine is operated in this "part-cylinder" mode.

Cylinder deactivation control strategy relies on setting maximum manifold absolute pressures or predicted torque ranges where it is acceptable to deactivate engine cylinders. Noise and vibration issues reduce the operating range where cylinder deactivation is allowed, although manufacturers continue exploring vehicle changes that enable increasing the amount of time that cylinder deactivation might be suitable. Some manufacturers may choose to adopt active engine mounts and/or active noise cancellation systems to address NVH concerns and allow a greater operating range of activation which is also shown in the cost estimates for this technology. Most manufacturers have legitimately stated that use of DEAC on 4 cylinder engines would cause unacceptable NVH; therefore, as in the MYs 2012-2016 rule and the 2010 TAR, the agencies are not applying cylinder deactivation to 4-cylinder engines in evaluating potential emission reductions/fuel economy improvements and associated costs.

Cylinder deactivation has seen a recent resurgence thanks to better valvetrain designs and engine controls. General Motors and Chrysler Group have incorporated cylinder deactivation across a substantial portion of their V8-powered vehicles and Honda offers V6 models with cylinder deactivation.

Effectiveness improvements scale roughly with engine displacement-to-vehicle weight ratio: the higher displacement-to-weight vehicles, operating at lower relative loads for normal driving, have the potential to operate in part-cylinder mode more frequently.

NHTSA and EPA reviewed estimates from the MYs 2012-2016 final rule, 2010 TAR, the RIA for the MYs 2014-2018 Medium and Heavy Duty GHG and Fuel Efficiency final rule. The lumped parameter model applied a 6 percent reduction in CO_2 emissions depending on vehicle class. The CAFE model, due to its incremental technology application capability, used a range depending on the engine valvetrain configuration. For example, DOHC engines already equipped with DCP and DVVLD achieve little benefit, 0.5 percent for DEACD, from adding cylinder deactivation since the pumping work has already been minimized and internal Exhaust Gas Recirculation (EGR) rates are maximized. However, SOHC engines, which have CCP and DVVLS applied, achieve effectiveness ranging from 2.5 to 3 percent for DEACS. And finally, OHV engines, without VVT or VVL technologies, achieved effectiveness for DEACO ranging from 3.9 to 5.5 percent.

For this final rule, consistent with the proposal, the agencies, taking into account the additional review and the work performed for the 2011 Ricardo study, have revised the effectiveness estimates for cylinder deactivation. The effectiveness relative to the base engine is 4.7 to 6.5 percent based on the lumped parameter model. Because of the incremental technology application capability of the CAFE model, NHTSA used the effectiveness range of 0.44 to 0.66 percent incremental for SOHC and DOHC applications. For OHV applications having no incremental application of VVT or VVL, the effectiveness was increased to a range of 4.66 to 6.30 percent.

In the MYs 2012-2016 final rule and the 2010 TAR, the agencies used a DMC estimate of $140 (2007$) and $157 (2007$) for cylinder deactivation technology on V6 and V8 engines, respectively. Adjusted for 2010$, the DMCs become $146 (2010$) and $165 (2010$) for this analysis and are considered applicable in MY 2015. This technology is considered to be on the flat-portion of the learning curve. The agencies have applied a low complexity ICM of 1.24 to this technology through 2018 and 1.19 thereafter. The resultant costs are shown in Table 3-25.

Table 3-25 Costs for Cylinder Deactivation (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	V6	$139	$136	$134	$131	$128	$126	$123	$121	$118
DMC	V8	$157	$153	$150	$147	$144	$142	$139	$136	$133
IC	V6	$56	$56	$42	$42	$42	$42	$42	$42	$42
IC	V8	$63	$63	$47	$47	$47	$47	$47	$47	$47
TC	V6	$196	$193	$176	$173	$170	$168	$165	$162	$160
TC	V8	$220	$217	$198	$195	$191	$189	$186	$183	$180

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

There is potential that, on engines already equipped with the mechanisms required for cylinder deactivation capability, the cost of DEAC as applied to SOHC and DOHC engines could be as low as $32 in MY 2017. This $32 accounts for the potential additional application of active engine mounts on SOHC and DOHC engines that, while having the potential to apply cylinder deactivation, may or would require these additional NVH improving devices for consumer acceptance. For this analysis, this additional expanded application and expense is only applied on 50 percent of the vehicles. Further, this SOHC and DOHC engine estimate is relevant to the CAFE model only because the OMEGA model does not apply technologies in the same incremental fashion as the CAFE model.

3.4.1.4 Variable Valve Timing (VVT)

Variable valve timing (VVT) encompasses a family of valve-train designs that alter the timing of the intake valve, exhaust valve, or both, primarily to reduce pumping losses, increase specific power, and control the level of residual gases in the cylinder. VVT reduces pumping losses when the engine is lightly loaded by controlling valve timing closer to an optimum needed to sustain horsepower and torque. VVT can also improve volumetric efficiency at higher engine speeds and loads. Additionally, VVT can be used to alter (and optimize) the effective compression ratio where it is advantageous for certain engine operating modes (*e.g.*, in the Atkinson Cycle).

VVT has now become a widely adopted technology: in MY 2011, approximately 93.8 percent of all new cars and light trucks had engines with some method of variable valve timing.[40] Manufacturers are currently using many different types of variable valve timing, which have a variety of different names and methods. Manufacturers are currently using many different types of variable valve timing, which have a variety of different names and methods. Therefore, the degree of further improvement across the fleet is limited by the level of valvetrain technology already implemented on the vehicles. Information found in the 2008 and 2010 baseline vehicle fleet files is used to determine the degree to which VVT technologies have already been applied to particular vehicles to ensure the proper level of VVT technology, if any, is applied. The three major types of VVT are listed below.

Each of the three implementations of VVT uses a cam phaser to adjust the camshaft angular position relative to the crankshaft position, referred to as "camshaft phasing." The phase adjustment results in changes to the pumping work required by the engine to accomplish the gas exchange process. The majority of current cam phaser applications use hydraulically-actuated units, powered by engine oil pressure and managed by a solenoid that controls the oil pressure supplied to the phaser.

3.4.1.4.1 Intake Cam Phasing (ICP)

Valvetrains with Intake Cam Phasing (ICP), which is the simplest of the cam phasing technologies, can modify the timing of the inlet valves by phasing the intake camshaft while the exhaust valve timing remains fixed. This requires the addition of a cam phaser on each bank of intake valves on the engine. An in-line 4-cylinder engine has one bank of intake valves, while V-configured engines have two banks of intake valves.

In the MYs 2012-2016 final rule and 2010 TAR, NHTSA and EPA assumed an effectiveness range of 2 to 3 percent for ICP. Based on the additional information from the

2011 Ricardo study and updated lumped parameter model the agencies have been able to fine-tuned the effectiveness range to be 2.1 to 2.7 percent for this analysis.

In the MYs 2012-2016 rule and the 2010 TAR, the agencies estimated the DMC of a single cam phaser for ICP at $37 (2007$). This DMC, adjusted for 2010$, becomes $39 (2010$) for this analysis and is considered applicable in the 2015 MY. This cost would be required for each cam shaft controlling intake valves. As such an OHC I4 and OHV V6 or V8 would need one cam phaser while an OHC V6 or V8 would need two cam phasers. This technology is considered to be on the flat-portion of the learning curve. The agencies have applied a low complexity ICM of 1.24 to this technology through 2018 and 1.19 thereafter. The resultant costs are shown in Table 3-26.

Table 3-26 Costs for VVT-Intake Cam Phasing - ICP (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	OHC-I4	$37	$36	$35	$35	$34	$33	$33	$32	$31
DMC	OHC-V6/V8	$74	$72	$71	$70	$68	$67	$65	$64	$63
DMC	OHV-V6/V8	$37	$36	$35	$35	$34	$33	$33	$32	$31
IC	OHC-I4	$9	$9	$7	$7	$7	$7	$7	$7	$7
IC	OHC-V6/V8	$19	$19	$15	$15	$15	$15	$15	$15	$15
IC	OHV-V6/V8	$9	$9	$7	$7	$7	$7	$7	$7	$7
TC	OHC-I4	$46	$46	$43	$42	$42	$41	$40	$40	$39
TC	OHC-V6/V8	$93	$91	$86	$84	$83	$82	$80	$79	$78
TC	OHV-V6/V8	$46	$46	$43	$42	$42	$41	$40	$40	$39

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; OHC=overhead cam; OHV=overhead valve; all costs are incremental to the baseline.

3.4.1.4.2 Coupled Cam Phasing (CCP)

Valvetrains with coupled (or coordinated) cam phasing can modify the timing of both the inlet valves and the exhaust valves an equal amount by phasing the camshaft of a single overhead cam (SOHC) engine or an overhead valve (OHV) engine. For SOHC engines, this requires the addition of a cam phaser on each bank of the engine. Thus, an in-line 4-cylinder engine has one cam phaser, while SOHC V-engines have two cam phasers. For OHV engines, which have only one camshaft to actuate both inlet and exhaust valves, CCP is the only VVT implementation option available and requires only one cam phaser.[ee]

The agencies' MYs 2012-2016 final rule estimated the effectiveness of CCP to be between 1 to 4 percent. Due to the incremental technology application capability of the

[ee] It is also noted that coaxial camshaft developments would allow other VVT options to be applied to OHV engines. However, since they would potentially be adopted on a limited number of OHV engines NHTSA did not include them in the decision tree.

CAFE model, NHTSA estimated the effectiveness for CCP to be 1 to 3 percent for a SOHC engine and 1 to 1.5 percent for an overhead valve engine.

For this final rule, consistent with the proposal, the agencies, have revised the estimates for CCP taking into account the additional review and the work performed for the 2011 Ricardo study. The effectiveness relative to the base engine is 4.1 to 5.5 percent based on the lumped parameter model. Because of the incremental nature of the CAFE model, NHTSA used the incremental effectiveness range of 4.14 to 5.36 percent for SOHC applications; an increase over the MYs 2012-16 final rule and 2010 TAR. For OHV applications, CCP was paired with discrete variable valve lift (DVVL) to form a new technology descriptor called variable valve actuation (VVA). Effectiveness values for this new descriptor is discussed later in Section 3.4.1.6.

In regard to CCP costs, the same cam phaser has been assumed for intake cam phasing as for coupled cam phasing, thus the DMCs for CCP is identical to those presented for ICP in Table 3-26.

3.4.1.4.3 Dual Cam Phasing (DCP)

The most flexible VVT design is dual (independent) cam phasing (DCP), where the intake and exhaust valve opening and closing events are controlled independently. This allows the option of controlling valve overlap, which can be used as an internal EGR strategy. At low engine loads, DCP creates a reduction in pumping losses, resulting in improved fuel consumption/reduced CO_2 emissions. Increased internal EGR also results in lower engine-out NO_X emissions. Fuel consumption and CO_2 emissions improvements enabled by DCP are dependent on the residual tolerance of the combustion system. Additional improvements are observed at idle, where low valve overlap could result in improved combustion stability, potentially reducing idle fuel consumption. For forward looking technology application, DCP is only applicable to dual overhead cam (DOHC) engines.[ff]

For the MYs 2012-2016 final rule and 2010 TAR, the EPA and NHTSA assumed an effectiveness range for DCP of 3 to 5 percent relative to a base engine or 2 to 3 relative to an engine with ICP. The agencies have updated this range, based on the updated lumped-parameter model, to be 4.1 to 5.5 percent relative to a base engine or 2.0 to 2.7 percent relative to an engine with ICP.

[ff] The agencies note at least one production implementation of an OHV dual cam phasing is included in the baseline fleet. This consisted of a single concentric camshaft (a "camshaft within a camshaft") and a single dual vane phaser assemblies enabling independent phasing of the intake and exhaust camshaft profiles. However, this technology was applied to a limited production sports car versus a mass market application with significant sales volume. The agencies are not aware of any similar application moving forward.

The costs for DCP are the same per phaser as described above for ICP. However, for DCP, an additional cam phaser is required for each camshaft controlling exhaust valves. As a result, a dual overhead cam I4 would need two phasers and a dual overhead cam V6 or V8 would need four phasers, and an overhead valve V engine would need two.[gg]

This technology is considered to be on the flat-portion of the learning curve. The agencies have applied a medium complexity ICM of 1.39 to this technology through 2018 and 1.29 thereafter. The resultant costs are shown in Table 3-27.

Table 3-27 Costs for VVT-Dual Cam Phasing (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	OHC-I4	$68	$66	$65	$64	$62	$61	$60	$59	$58
DMC	OHC-V6/V8	$146	$143	$140	$137	$134	$132	$129	$127	$124
DMC	OHV-V6/V8	$74	$72	$71	$70	$68	$67	$65	$64	$63
IC	OHC-I4	$27	$27	$20	$20	$20	$20	$20	$20	$20
IC	OHC-V6/V8	$59	$59	$44	$44	$44	$44	$44	$44	$44
IC	OHV-V6/V8	$30	$30	$22	$22	$22	$22	$22	$22	$22
TC	OHC-I4	$95	$94	$86	$84	$83	$82	$80	$79	$78
TC	OHC-V6/V8	$205	$202	$184	$181	$178	$176	$173	$170	$168
TC	OHV-V6/V8	$104	$102	$93	$92	$90	$89	$88	$86	$85

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; OHC=overhead cam; OHV=overhead valve; all costs are incremental to the baseline.

3.4.1.5 Variable Valve Lift (VVL)

Varying and controlling the amount of cylinder valve lift across and engine operating range provides a potential for further efficiency improvements. By optimizing the valve-lift profile for specific engine operating regions, the pumping losses can be reduced by reducing the amount of throttling required to produce the desired engine power output. By moving the throttling losses further downstream of the throttle valve, the heat transfer losses that occur from the throttling process are directed into the fresh charge-air mixture just prior to compression, delaying the onset of knock-limited combustion processes. Variable valve lift control can also be used to induce in-cylinder mixture motion, which improves fuel-air mixing and can result in improved thermodynamic efficiency. Variable valve lift control can also potentially reduce overall valvetrain friction. At the same time, such systems may also incur increased parasitic losses associated with their actuation mechanisms. A number of manufacturers have already implemented VVL into their fleets (Toyota, Honda, and BMW), but overall this technology is still available as an efficiency improving technology for most of the fleet. There are two major classifications of variable valve lift, described below:

[gg] *Ibid*.

3.4.1.5.1 Discrete Variable Valve Lift (DVVL)

Discrete variable valve lift (DVVL) systems allow the selection between two or three discrete cam profiles by means of a hydraulically-actuated mechanical system. These cam profiles consist of a low and a high-lift lobe, and may include an inert or blank lobe to incorporate cylinder deactivation (in the case of a 3-step DVVL system). DVVL is normally applied together with VVT control. DVVL is also known as Cam Profile Switching (CPS). DVVL is a mature technology with low technical risk.

The effectiveness of DVVL has been estimated to range from 1 to 4 percent in addition to that realized by VVT systems. These values were based on the research supporting MYs 2012-16 final rule, confidential manufacturer data, and a research conducted by the Northeast States Center for a Clean Air Future (NESCCAF). Based on additional information contained in the 2011 Ricardo study, NHTSA and EPA have revised the effectiveness range of DVVL systems to 2.8 to 3.9 percent above that realized by VVT systems.

In the MYs 2012-2016 rule and the 2010 TAR, the agencies estimated the DMC of DVVL at \$116 (2007\$), \$169 (2007\$) and \$241 (2007\$) for an I4, V6 and V8 engine, respectively. Adjusted for 2010\$, these DMCs become \$122 (2010\$), \$177 (2010\$) and \$253 (2010\$) for this analysis all of which are considered applicable in MY 2015. This technology is considered to be on the flat-portion of the learning curve and is applicable only to engines with overhead cam configurations. The agencies have applied a medium complexity ICM of 1.39 to this technology through 2018 and 1.29 thereafter. The resultant costs are shown in Table 3-28.

Table 3-28 Costs for Discrete Variable Valve Lift – DVVL (2010\$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	OHC-I4	\$116	\$114	\$111	\$109	\$107	\$105	\$103	\$101	\$99
DMC	OHC-V6	\$168	\$165	\$161	\$158	\$155	\$152	\$149	\$146	\$143
DMC	OHC-V8	\$240	\$235	\$231	\$226	\$222	\$217	\$213	\$209	\$204
IC	OHC-I4	\$47	\$47	\$35	\$35	\$35	\$35	\$35	\$35	\$35
IC	OHC-V6	\$68	\$68	\$51	\$51	\$51	\$50	\$50	\$50	\$50
IC	OHC-V8	\$97	\$97	\$73	\$72	\$72	\$72	\$72	\$72	\$72
TC	OHC-I4	\$163	\$161	\$146	\$144	\$142	\$140	\$137	\$135	\$133
TC	OHC-V6	\$236	\$233	\$212	\$209	\$206	\$202	\$199	\$196	\$193
TC	OHC-V8	\$338	\$333	\$303	\$298	\$294	\$289	\$285	\$280	\$276

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; OHC=overhead cam; OHV=overhead valve; all costs are incremental to the baseline.

3.4.1.5.2 Continuously Variable Valve Lift (CVVL)

In CVVL systems, valve lift is varied by means of a mechanical linkage, driven by an actuator controlled by the engine control unit. The valve opening and phasing vary as the lift is changed and the relation depends on the geometry of the mechanical system. BMW has considerable production experience with CVVL systems and has sold port-injected "Valvetronic" engines since 2001. Fiat is now offering "MultiAir" engines enabling precise control over intake valve lift. CVVL allows the airflow into the engine to be regulated by means of intake valve opening reduction, which improves engine efficiency by reducing pumping losses from throttling the intake system further upstream as with a conventionally throttled engine.

Variable valve lift gives a further reduction in pumping losses compared to that which can be obtained with cam phase control only, with CVVL providing greater effectiveness than DVVL, since it can be fully optimized for all engine speeds and loads, and is not limited to a two or three step compromise. There may also be a small reduction in valvetrain friction when operating at low valve lift, resulting in improved low load fuel consumption for cam phase control with variable valve lift as compared to cam phase control only. Most of the fuel economy effectiveness is achieved with variable valve lift on the intake valves only. CVVL is only applicable to double overhead cam (DOHC) engines.

The MYs 2012-2016 final rule estimated the effectiveness for CVVL at 1.5 to 3.5 percent over an engine with DCP, but also recognized that it could go up as high as 5 percent above and beyond DCP to account for the implementation of more complex CVVL systems such as BMW's "Valvetronic" and Fiat "MultiAir" systems. Thus, the effectiveness range for CVVL in this Joint TSD ranges from 1.5 to 7 percent depending on the complexity level of the application

. For this rulemaking, NHTSA has increased the incremental effectiveness values for this technology to a range of 3.6 to 4.9 percent from 1.5 to 3.5 percent in the MYs 2012-2016 final rule.

In the 2012-2016 rule and the 2010 TAR, the agencies estimated the DMC of CVVL at $174 (2007$), $320 (2007$), $349 (2007$), $866 (2007$) and $947 (2007$) for an OHC-I4, OHC-V6, OHC-V8, OHV-V6 and OHV-V8 engine, respectively. Adjusted for 2010$, these DMCs become $183 (2010$), $335 (2010$), $366 (2010$), $893 (2010$) and $977 (2010$) for this analysis all of which are considered applicable in MY 2015. As indicated in this section, CVVL is considered only applicable to DOHC engine designs. The DMCs for OHV engines are meant to reflect additional costs associated with moving to a DOHC engine design.

This technology is considered to be on the flat-portion of the learning curve. The agencies have applied a medium complexity ICM of 1.39 to this technology through 2018 and 1.29 thereafter. The resultant costs are shown in Table 3-29.

Table 3-29 Costs for Continuous Variable Valve Lift – CVVL (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	OHC-I4	$174	$170	$167	$164	$160	$157	$154	$151	$148
DMC	OHC-V6	$319	$313	$306	$300	$294	$288	$283	$277	$271
DMC	OHC-V8	$348	$341	$334	$327	$321	$314	$308	$302	$296
DMC	OHV-V6	$857	$840	$823	$807	$791	$775	$760	$744	$729
DMC	OHV-V8	$937	$919	$901	$883	$865	$847	$830	$814	$798
IC	OHC-I4	$70	$70	$53	$52	$52	$52	$52	$52	$52
IC	OHC-V6	$129	$129	$96	$96	$96	$96	$96	$95	$95
IC	OHC-V8	$141	$141	$105	$105	$105	$104	$104	$104	$104

IC	OHV-V6	$347	$346	$259	$259	$258	$258	$257	$257	$256
IC	OHV-V8	$380	$379	$283	$283	$282	$282	$281	$281	$280
TC	OHC-I4	$244	$241	$220	$216	$213	$209	$206	$203	$200
TC	OHC-V6	$448	$441	$403	$396	$390	$384	$378	$372	$367
TC	OHC-V8	$489	$482	$439	$432	$426	$419	$412	$406	$400
TC	OHV-V6	$1,205	$1,187	$1,083	$1,066	$1,048	$1,032	$1,016	$1,001	$986
TC	OHV-V8	$1,317	$1,298	$1,184	$1,166	$1,147	$1,129	$1,112	$1,095	$1,078
DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; OHC=overhead cam; OHV=overhead valve; all costs are incremental to the baseline.										

3.4.1.6 Variable Valve Actuation (VVA)

For this final rule, consistent with the proposal, NHTSA has combined two valve control technologies for OHV engines. Coupled cam phasing (CCPO) and discrete valve lift (DVVLO) into one technology defined as variable valve actuation (VVA). The agency estimates the incremental effectiveness for VVA applied to and OHV engine as 2.71 to 3.59 percent. This effectiveness value is slightly lower than coupled cam phasing for overhead cam applications (CCPS) based on the assumption that VVA would be applied to an OHV engine after cylinder deactivation (DEAC). For more information on combining these technologies please refer to NHTSA's FRIA.

3.4.1.7 Stoichiometric Gasoline Direct Injection (SGDI)

Stoichiometric gasoline direct injection (SGDI), or Spark Ignition Direct injection (SIDI), engines inject fuel at high pressure directly into the combustion chamber (rather than the intake port in port fuel injection). SGDI requires changes to the injector design, an additional high pressure fuel pump, new fuel rails to handle the higher fuel pressures and changes to the cylinder head and piston crown design. Direct injection of the fuel into the cylinder improves cooling of the air/fuel charge within the cylinder, which allows for higher compression ratios and increased thermodynamic efficiency without the onset of combustion knock. Recent injector design advances, improved electronic engine management systems and the introduction of multiple injection events per cylinder firing cycle promote better mixing of the air and fuel, enhance combustion rates, increase residual exhaust gas tolerance and improve cold start emissions. SGDI engines achieve higher power density and match well with other technologies, such as boosting and variable valvetrain designs.

Several manufacturers are manufacturing vehicles with SGDI engines, including VW/Audi, BMW, Toyota, Ford, and General Motors. Additionally, BMW, GM, Ford and VW/Audi have announced plans to significantly increase the number of SGDI engines in their portfolios.

NHTSA and EPA reviewed estimates from the MYs 2012-2016 final rule and 2010 TAR, which stated an effectiveness range of SGDI to be between 2 and 3 percent. NHTSA and EPA reviewed estimates from the Alliance of Automobile Manufactures, which projects 3 percent gains in fuel efficiency and a 7 percent improvement in torque. The torque increase provides the opportunity to downsize the engine allowing an increase in efficiency of up to a 5.8 percent. NHTSA and EPA also reviewed other published literature, reporting 3 percent effectiveness for SGDI.[41] Confidential manufacturer data reported an efficiency effectiveness range of 1 to 2 percent. Based on data from the 2011 Ricardo study and reconfiguration of the new lumped parameter model, EPA and NHTSA have revised this value to 1.5 percent[hh]. Combined with other technologies (*i.e.*, boosting, downsizing, and in some cases, cooled EGR), SGDI can achieve greater reductions in fuel consumption and CO_2 emissions compared to engines of similar power output.

The NHTSA and EPA cost estimates for SGDI take into account the changes required to the engine hardware, engine electronic controls, ancillary and Noise Vibration and Harshness (NVH) mitigation systems. Through contacts with industry NVH suppliers, and manufacturer press releases, the agencies believe that the NVH treatments will be limited to the mitigation of fuel system noise, specifically from the injectors and the fuel lines and have included corresponding cost estimates for these NVH controls. In the 2012-2016 FRM, the agencies estimated the DMC for SGDI at $213 (2007$), $321 (2007$) and $386 (2007$) for I3/I4, V6 and V8 engines, respectively. Adjusted for 2010$, these DMCs become $222 (2010$), $334 (2010$) and $402 (2010$) for this analysis all of which are considered applicable in MY 2012. This technology is considered to be on the flat-portion of the learning curve. The agencies have applied a medium complexity ICM of 1.39 to this technology through 2018 and 1.29 thereafter. The resultant costs are shown in Table 3-30.

Table 3-30 Costs for Stoichiometric Gasoline Direct Injection (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	I3/I4	$192	$188	$185	$181	$177	$174	$170	$167	$164
DMC	V6	$290	$284	$278	$273	$267	$262	$257	$251	$246
DMC	V8	$348	$341	$335	$328	$321	$315	$309	$302	$296
IC	I3/I4	$84	$84	$63	$63	$63	$63	$63	$62	$62
IC	V6	$127	$127	$95	$95	$95	$94	$94	$94	$94
IC	V8	$153	$153	$114	$114	$114	$114	$113	$113	$113
TC	I3/I4	$277	$273	$248	$244	$240	$236	$233	$229	$226
TC	V6	$417	$411	$373	$367	$362	$356	$351	$346	$340
TC	V8	$501	$494	$449	$442	$435	$429	$422	$416	$409

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

3.4.1.8 Turbocharging and Downsizing (TRBDS)

The specific power of a naturally aspirated engine is primarily limited by the rate at which the engine is able to draw air into the combustion chambers. Turbocharging and supercharging (grouped together here as boosting) are two methods to increase the intake manifold pressure and cylinder charge-air mass above naturally aspirated levels. Boosting increases the airflow into the engine, thus increasing the specific power level, and with it the ability to reduce engine displacement while maintaining performance. This effectively reduces the pumping losses at lighter loads in comparison to a larger, naturally aspirated engine.

[hh] However, because GDI is a key enabler for modern, highly downsized turbocharged engines, this difference will be overshadowed by the higher effectiveness for turbocharging and downsizing when they are combined into packages.

Almost every major manufacturer currently markets a vehicle with some form of boosting. While boosting has been a common practice for increasing performance for several decades, turbocharging has considerable potential to improve fuel economy and reduce CO_2 emissions when the engine displacement is also reduced. Specific power levels for a boosted engine often exceed 100 hp/L, compared to average naturally aspirated engine power densities of roughly 70 hp/L. As a result, engines can be downsized roughly 30 percent or higher while maintaining similar peak output levels. In the last decade, improvements to turbocharger turbine and compressor design have improved their reliability and performance across the entire engine operating range. New variable geometry turbines and ball-bearing center cartridges allow faster turbocharger spool-up (virtually eliminating the once-common "turbo lag") while maintaining high flow rates for increased boost at high engine speeds. Low speed torque output has been dramatically improved for modern turbocharged engines. However, even with turbocharger improvements, maximum engine torque at very low engine speed conditions, for example launch from standstill, is increased less than at mid and high engine speed conditions. The potential to downsize engines may be less on vehicles with low displacement to vehicle mass ratios for example a very small displacement engine in a vehicle with significant curb weight, in order to provide adequate acceleration from standstill, particularly up grades or at high altitudes.

Use of GDI systems with turbocharged engines and air-to-air charge air cooling also reduces the fuel octane requirements for knock limited combustion and allows the use of higher compression ratios. Ford's "Ecoboost" downsized, turbocharged GDI engines introduced on MY 2010 vehicles allow the replacement of V8 engines with V6 engines with improved in 0-60 mph acceleration and with fuel economy improvements of up to 12 percent.[42]

Recently published data with advanced spray-guided injection systems and more aggressive engine downsizing targeted towards reduced fuel consumption and CO_2 emissions reductions indicate that the potential for reducing CO_2 emissions for turbocharged, downsized GDI engines may be as much as 15 to 30 percent relative to port-fuel-injected engines.[27,28,29,30,31] Confidential manufacturer data suggests an incremental range of fuel consumption and CO_2 emission reduction of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption and CO_2 emission reduction of 8 to 13 percent compared to current-production naturally-aspirated engines without friction reduction or other fuel economy technologies: a joint technical paper by Bosch and Ricardo suggesting fuel economy gain of 8 to 10 percent for downsizing from a 5.7 liter port injection V8 to a 3.6 liter V6 with direct injection using a wall-guided direct injection system;[43] a Renault report suggesting a 11.9 percent NEDC fuel consumption gain for downsizing from a 1.4 liter port injection in-line 4-cylinder engine to a 1.0 liter in-line 4-cylinder engine, also with wall-guided direct injection;[44] and a Robert Bosch paper suggesting a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with wall-guided injection.[45] These reported fuel economy benefits show a wide range depending on the SGDI technology employed.

NHTSA and EPA reviewed estimates from the 2012-2016 final rule, the TAR, and existing public literature. The previous estimate from the MYs 2012-2016 suggested a 12 to 14 percent effectiveness improvement, which included low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, over baseline fixed-valve engines, similar to the estimate for Ford's Ecoboost engine, which is already in production. Additionally, the agencies analyzed Ricardo vehicle simulation data for various turbocharged engine packages. Based on this data, and considering the widespread nature of the public estimates, the effectiveness of turbocharging and downsizing is highly dependent upon implementation and degree of downsizing.

In alignment with these variances, for this final rule, consistent with the proposal, the agencies evaluated 4 different levels of downsized and turbocharged high Brake Mean Effective Pressure (BMEP)[ii]. engines; 18-bar, 24-bar, 24-bar with cooled exhaust gas recirculation (EGR) and 27-bar with cooled EGR All engines are assumed to include gasoline direct injection (SGDI) and effectiveness values include the benefits of this technology. In addition, the agencies believe to implement in production a 27 bar boost level, it is necessary to incorporate cooled exhaust gas recirculation (EGR) and also require a 2-stage turbocharger as well as engine changes to increase robustness. The cooled EGR technology is discussed later in this section.

NHTSA and EPA have revised the effectiveness to reflect this new information and assume that turbocharging and downsizing, alone, will provide a 12 to 24.6 percent effectiveness improvement (dependent upon degree of downsizing and boost levels) over naturally aspirated, fixed-valve engines. More specifically, 12.1 to 14.9 percent for 18-bar engines, which is equal to the boost levels evaluated in the MYs 2012-2016 final rule, assuming 33 percent downsizing, 16.4 to 20.1 percent for 24-bar engines, assuming 50 percent downsizing, 19.3 to 23.0 percent for 24-bar engines with cooled EGR, assuming 50 percent downsizing and 20.6 to 24.6 percent for 27-bar engines with cooled EGR, assuming 56 percent downsizing. For comparison purposes an 18-bar engine with low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, which is equivalent to MYs 2012-2016 assumed turbocharging and downsizing technology, now results in a 16.8 to 20.9 percent effectiveness improvement. Coupling turbocharging and downsizing with low friction lubricant (level one and two), engine friction reductions (level one and two), DCP, DVVL and SGDI, for the MYs 2017-2025 timeframe, yields 18.0 to 22.4 percent for 18-bar engines 20.4 to 25.2 percent for 24-bar engines, 23.2 to 27.9 percent for 24-bar engine with cooled EGR and 24.0 to 28.8 percent for 27-bar with cooled EGR over naturally aspirated, fixed-valve engines.

As noted above, the agencies relied on engine teardown analyses conducted by EPA, FEV and Munro to develop costs for turbocharged GDI engines.[46] In the 2012-2016 FRM, the agencies estimated the DMC for turbocharging to 18 bar BMEP at $404 (2007$) and $681 (2007$) for I4 and V6/V8 engines, respectively, where the higher cost for the V-configuration

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[ii] Brake Mean Effective Pressure is the average amount of pressure in pounds per square inch (psi) that must be exerted on the piston to create the measured horsepower. This indicates how effective an engine is at filling the combustion chamber with an air/fuel mixture, compressing it and achieving the most power from it. A higher BMEP value contributes to higher overall efficiency.

engines represents twin turbochargers versus the single turbocharger in the I-configuration engine. These DMCs become $420 (2010$) and $708 (2010$), respectively, for this analysis. In the 2010 TAR, the agencies presented costs for 24 bar BMEP turbocharging at 1.5x the cost of the 18 bar BMEP technology. This additional cost covered the incremental cost increase of a variable geometry turbocharger (see 2010 TAR at page B-12). Thus, the DMC for 24 bar BMEP would be $630 (2010$) and $1,062 (2010$) for I-configuration and V-configuration engines, respectively. Note also for this final rule, the agencies are estimating the DMC of the 27 bar BMEP technology at 2.5x the 18 bar BMEP technology, or $1,050 (2010$) and $1,771 (2010$) for I-configuration and V-configuration engines, respectively. All of these turbocharger-related DMCs are considered applicable in the 2012MY. The agencies consider each turbocharger technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2018 for 18 bar and through 2024 for 24 and 27 bar, then 1.29 to each thereafter. The resultant costs are shown in Table 3-31.

Table 3-31 Costs for Turbocharging (2010$)

Cost type	Technology (BMEP)	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	18 bar	I-engine	$365	$357	$350	$343	$336	$330	$323	$316	$310
DMC	18 bar	V-engine	$614	$602	$590	$578	$567	$555	$544	$533	$523
DMC	24 bar	I-engine	$547	$536	$525	$515	$504	$494	$484	$475	$465
DMC	24 bar	V-engine	$922	$903	$885	$867	$850	$833	$816	$800	$784
DMC	27 bar	I-engine	$911	$893	$875	$858	$841	$824	$807	$791	$775
DMC	27 bar	V-engine	$1,536	$1,505	$1,475	$1,446	$1,417	$1,389	$1,361	$1,334	$1,307
IC	18 bar	I-engine	$160	$160	$120	$119	$119	$119	$119	$118	$118
IC	18 bar	V-engine	$270	$270	$202	$201	$201	$200	$200	$200	$199
IC	24 bar	I-engine	$240	$240	$239	$239	$238	$238	$238	$237	$177
IC	24 bar	V-engine	$405	$404	$403	$403	$402	$401	$400	$400	$299
IC	27 bar	I-engine	$401	$400	$399	$398	$397	$397	$396	$395	$296
IC	27 bar	V-engine	$675	$674	$672	$671	$670	$669	$667	$666	$499
TC	18 bar	I-engine	$525	$517	$470	$462	$455	$448	$442	$435	$428
TC	18 bar	V-engine	$885	$872	$792	$779	$768	$756	$744	$733	$722
TC	24 bar	I-engine	$787	$776	$765	$754	$743	$732	$722	$712	$643
TC	24 bar	V-engine	$1,327	$1,308	$1,289	$1,270	$1,252	$1,234	$1,217	$1,200	$1,083
TC	27 bar	I-engine	$1,312	$1,293	$1,274	$1,256	$1,238	$1,220	$1,203	$1,186	$1,071
TC	27 bar	V-engine	$2,211	$2,179	$2,148	$2,117	$2,087	$2,057	$2,028	$2,000	$1,805

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

The costs for the downsizing portion of the turbo/downsize technology is more complex. The agencies have described those cost and how they were developed—based primarily on FEV teardowns but some were scaled based on teardowns to generate costs for downsizing situations that were not covered by teardowns—in both the 2012-2016 FRM and the 2010 TAR. The DMCs used for this analysis are identical to those used in the 2010 TAR except that they have been updated to 2010 dollars. Notable is the fact that many of the downsizing costs are negative because they result in fewer parts and less material than the engine from which they are "derived." For example a V8 engine could be replaced by a turbocharged V6 engine having two fewer cylinders and as many as eight fewer valves (in the case of a V8 DOHC downsized to a V6 DOHC). Importantly, the agencies have used an approach to calculating indirect costs that results in positive indirect costs regardless of whether the DMC is positive or negative. This is done by calculating indirect costs based on the absolute value of the DMC, then adding the indirect cost to the DMC to arrive at the total cost. This way, the agencies are never making a negative DMC "more negative" when accounting for the indirect costs. This approach has been used in the 2012-2016 final rule and the 2010 TAR. Given the history of the downsizing costs used by the agencies, many are considered applicable in the 2012MY and many in the 2017MY.[jj] All are considered to be on the flat portion of the learning curve. The agencies have applied a medium complexity ICM of 1.39 through 2018 and 1.29 thereafter. The resultant costs are shown in Table 3-32.

Table 3-32 Costs for Engine Downsizing (2010$)

Cost type	Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	I4 DOHC to I3	-$174	-$171	-$167	-$164	-$161	-$157	-$154	-$151	-$148
DMC	I4 DOHC to I4	-$77	-$75	-$74	-$72	-$71	-$69	-$68	-$67	-$65
DMC	V6 DOHC to I4	-$494	-$484	-$474	-$465	-$455	-$446	-$437	-$429	-$420
DMC	V6 SOHC 2V to I4	-$345	-$338	-$331	-$325	-$318	-$312	-$306	-$300	-$294
DMC	V6 OHV to I4	$281	$272	$264	$256	$249	$241	$236	$232	$227
DMC	V8 DOHC to I4	-$854	-$828	-$804	-$779	-$756	-$733	-$719	-$704	-$690
DMC	V8 DOHC to V6	-$247	-$242	-$237	-$233	-$228	-$223	-$219	-$215	-$210
DMC	V8 SOHC 2V to I4	-$656	-$637	-$617	-$599	-$581	-$564	-$552	-$541	-$530
DMC	V8 SOHC 3V to I4	-$731	-$709	-$687	-$667	-$647	-$627	-$615	-$603	-$591
DMC	V8 SOHC 2V to V6	-$76	-$74	-$73	-$71	-$70	-$68	-$67	-$66	-$64
DMC	V8 SOHC 3V to V6	-$140	-$137	-$135	-$132	-$129	-$127	-$124	-$122	-$119
DMC	V8 OHV to I4	-$242	-$234	-$227	-$220	-$214	-$207	-$203	-$199	-$195
DMC	V8 OHV to V6	$328	$318	$308	$299	$290	$281	$276	$270	$265
IC	I4 DOHC to I3	$77	$76	$57	$57	$57	$57	$57	$57	$57
IC	I4 DOHC to I4	$34	$34	$25	$25	$25	$25	$25	$25	$25
IC	V6 DOHC to I4	$217	$217	$162	$162	$161	$161	$161	$161	$160
IC	V6 SOHC 2V to I4	$152	$151	$113	$113	$113	$113	$112	$112	$112
IC	V6 OHV to I4	$109	$108	$81	$81	$80	$80	$80	$80	$80
IC	V8 DOHC to I4	$331	$330	$246	$245	$244	$244	$243	$243	$242
IC	V8 DOHC to V6	$109	$108	$81	$81	$81	$81	$80	$80	$80
IC	V8 SOHC 2V to I4	$254	$253	$189	$188	$188	$187	$187	$187	$186
IC	V8 SOHC 3V to I4	$283	$282	$210	$210	$209	$208	$208	$208	$207
IC	V8 SOHC 2V to V6	$33	$33	$25	$25	$25	$25	$25	$25	$25
IC	V8 SOHC 3V to V6	$62	$61	$46	$46	$46	$46	$46	$46	$45
IC	V8 OHV to I4	$94	$93	$70	$69	$69	$69	$69	$69	$69
IC	V8 OHV to V6	$127	$126	$94	$94	$94	$93	$93	$93	$93
TC	I4 DOHC to I3	-$98	-$94	-$110	-$107	-$104	-$101	-$98	-$95	-$92

[jj] The engine downsize costs based on actual FEV teardowns were considered applicable to the 2012MY, as was explained for some downsize costs in the 2012-2016 final rule and others in the 2010 TAR. For other downsize costs—the two changes from OHV engines to DOHC engines—the agencies did not use FEV teardowns or extrapolations from FEV teardowns, and instead used the methodology employed in the 2008 EPA Staff Report, a methodology determined by both agencies to result in cost estimates more appropriate for the 2017MY. The new downsize costs—those for V8 engines downsized to I4 engines—use a combination of V8 to V6 then V6 to I4 downsize costs and are considered applicable to the 2017MY within the context of this analysis.

TC	I4 DOHC to I4	-$43	-$41	-$48	-$47	-$46	-$44	-$43	-$42	-$40
TC	V6 DOHC to I4	-$277	-$267	-$312	-$303	-$294	-$285	-$277	-$268	-$260
TC	V6 SOHC 2V to I4	-$193	-$187	-$218	-$212	-$205	-$199	-$193	-$187	-$182
TC	V6 OHV to I4	$390	$381	$345	$337	$329	$321	$316	$311	$307
TC	V8 DOHC to I4	-$523	-$499	-$558	-$534	-$512	-$490	-$476	-$462	-$448
TC	V8 DOHC to V6	-$139	-$134	-$156	-$152	-$147	-$143	-$138	-$134	-$130
TC	V8 SOHC 2V to I4	-$402	-$383	-$429	-$411	-$393	-$376	-$365	-$355	-$344
TC	V8 SOHC 3V to I4	-$448	-$427	-$477	-$457	-$438	-$419	-$407	-$395	-$383
TC	V8 SOHC 2V to V6	-$42	-$41	-$48	-$46	-$45	-$44	-$42	-$41	-$40
TC	V8 SOHC 3V to V6	-$79	-$76	-$89	-$86	-$83	-$81	-$78	-$76	-$74
TC	V8 OHV to I4	-$148	-$141	-$158	-$151	-$145	-$139	-$134	-$131	-$127
TC	V8 OHV to V6	$454	$444	$403	$393	$384	$375	$369	$363	$358

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline; all resultant engines are DOHC.

Note that the V8 to I4 engine downsize is new for this final rule, consistent with the proposal. This level of engine downsizing is considered for this analysis only if it also includes 27 bar BMEP turbo boost which, in addition, requires the addition of cooled EGR (discussed below). As a result, any 27 bar BMEP engine in this analysis will be I4 configuration and will include cooled EGR.

With the information shown in Table 3-31 and Table 3-32, the costs for any turbo/downsize change can be determined. These costs are shown in Table 3-33.

Table 3-33 Total Costs for Turbo/Downsizing (2010$)

Downsize Technology	Turbo Technology (BMEP)	2017	2018	2019	2020	2021	2022	2023	2024	2025
I4 DOHC to I3	18 bar	$427	$423	$359	$356	$352	$348	$344	$340	$337
I4 DOHC to I3	24 bar	$690	$681	$654	$647	$639	$632	$624	$617	$551
I4 DOHC to I3	27 bar	$1,214	$1,199	$1,164	$1,149	$1,134	$1,120	$1,106	$1,092	$979
I4 DOHC to I4	18 bar	$482	$476	$421	$415	$410	$404	$399	$393	$388
I4 DOHC to I4	24 bar	$744	$734	$716	$707	$697	$688	$679	$670	$602
I4 DOHC to I4	27 bar	$1,269	$1,251	$1,226	$1,209	$1,192	$1,176	$1,160	$1,145	$1,031
V6 DOHC to I4	18 bar	$248	$250	$157	$159	$161	$163	$165	$167	$169
V6 DOHC to I4	24 bar	$510	$508	$452	$450	$449	$447	$445	$444	$383
V6 DOHC to I4	27 bar	$1,035	$1,026	$962	$953	$944	$935	$927	$918	$811
V6 SOHC 2V to I4	18 bar	$331	$330	$251	$251	$250	$249	$248	$248	$247
V6 SOHC 2V to I4	24 bar	$594	$589	$546	$542	$537	$533	$529	$524	$461
V6 SOHC 2V to I4	27 bar	$1,119	$1,106	$1,056	$1,044	$1,032	$1,021	$1,010	$999	$890
V6 OHV to I4	18 bar	$914	$898	$815	$799	$784	$770	$758	$746	$735
V6 OHV to I4	24 bar	$1,177	$1,156	$1,110	$1,090	$1,072	$1,053	$1,038	$1,023	$949
V6 OHV to I4	27 bar	$1,701	$1,674	$1,619	$1,593	$1,567	$1,542	$1,519	$1,498	$1,378
V8 DOHC to I4	18 bar	$1	$18	-$88	-$72	-$56	-$41	-$34	-$27	-$19
V8 DOHC to I4	24 bar	$264	$277	$207	$219	$231	$243	$246	$250	$195
V8 DOHC to I4	27 bar	$789	$794	$716	$722	$726	$731	$728	$725	$623
V8 DOHC to V6	18 bar	$746	$738	$635	$628	$620	$613	$606	$599	$592
V8 DOHC to V6	24 bar	$1,188	$1,174	$1,132	$1,118	$1,105	$1,092	$1,078	$1,066	$953
V8 DOHC to V6	27 bar	$2,073	$2,045	$1,991	$1,965	$1,940	$1,914	$1,890	$1,866	$1,675

V8 SOHC 2V to I4	18 bar	$123	$134	$41	$52	$62	$72	$76	$80	$84
V8 SOHC 2V to I4	24 bar	$385	$392	$336	$343	$350	$356	$357	$357	$298
V8 SOHC 2V to I4	27 bar	$910	$910	$846	$845	$845	$844	$838	$832	$727
V8 SOHC 3V to I4	18 bar	$77	$90	-$8	$5	$18	$29	$35	$40	$45
V8 SOHC 3V to I4	24 bar	$339	$349	$287	$296	$305	$313	$315	$317	$259
V8 SOHC 3V to I4	27 bar	$864	$866	$797	$799	$800	$801	$796	$791	$688
V8 SOHC 2V to V6	18 bar	$842	$831	$744	$733	$723	$712	$702	$692	$682
V8 SOHC 2V to V6	24 bar	$1,284	$1,267	$1,241	$1,224	$1,207	$1,191	$1,175	$1,159	$1,043
V8 SOHC 2V to V6	27 bar	$2,169	$2,138	$2,100	$2,071	$2,042	$2,014	$1,986	$1,959	$1,766
V8 SOHC 3V to V6	18 bar	$806	$796	$703	$693	$684	$675	$666	$657	$648
V8 SOHC 3V to V6	24 bar	$1,248	$1,232	$1,200	$1,184	$1,169	$1,153	$1,138	$1,124	$1,010
V8 SOHC 3V to V6	27 bar	$2,133	$2,103	$2,059	$2,031	$2,003	$1,976	$1,950	$1,924	$1,732
V8 OHV to I4	18 bar	$377	$376	$312	$311	$311	$310	$307	$304	$302
V8 OHV to I4	24 bar	$639	$635	$607	$602	$598	$594	$587	$581	$516
V8 OHV to I4	27 bar	$1,164	$1,152	$1,116	$1,105	$1,093	$1,082	$1,069	$1,056	$944
V8 OHV to V6	18 bar	$1,339	$1,316	$1,194	$1,172	$1,151	$1,131	$1,113	$1,096	$1,080
V8 OHV to V6	24 bar	$1,781	$1,752	$1,691	$1,663	$1,636	$1,609	$1,586	$1,563	$1,441
V8 OHV to V6	27 bar	$2,666	$2,623	$2,550	$2,510	$2,471	$2,432	$2,397	$2,363	$2,163

All costs are total costs (Direct manufacturing costs + Indirect costs); all costs are incremental to the baseline; all resultant engines are DOHC; note that costs are shown for 27 bar BMEP engines with V6 engines. In fact, the agencies do not believe that manufacturers will employ 27 bar BMEP technology on V6 engines to comply with the final standards, instead using the additional boost to allow for downsizing V6 engines to smaller I4 engines than would be used for 18 bar BMEP or 24 bar BMEP I4 engines and/or downsizing V8 engines to I4 engines. As a result, whenever a 27 bar BMEP engine is chosen by either agency's model, the engine configuration will be an I4 and will include cooled EGR, as discussed in section 3.4.1.8.

3.4.1.9 Cooled Exhaust-Gas Recirculation (EGR)

While not considered in the technology packages used for assessing potential compliance pathways in the 2012-2016 light-duty rule, the agencies have considered an emerging technology referred to as cooled exhaust gas recirculation (cooled-EGR) as applied to downsized, turbocharged GDI engines. In the 2010 TAR, the agencies considered this technology as an advanced gasoline technology since it was considered an emerging and not yet available technology in the light-duty gasoline market. While a cooled or "boosted" EGR technology was discussed in the 2012-2016 light-duty rule record, the technology considered here is comparatively more advanced as described in the 2010 TAR. As such, the agencies have considered new costs and new effectiveness values for it. The effectiveness values used for vehicle packages with cooled EGR within this analysis reflect a conservative estimate of system performance at approximately 24-bar BMEP. Vehicle simulation modeling of technology packages using the more highly boosted and downsized cooled EGR engines (up to 27-bar BMEP, and utilizing EGR rates of 20-25%) with dual-stage turbocharging has been completed as part of EPA's contract with Ricardo Engineering as described in 3.3.1.2. For this FRM, consistent with the proposal, the agencies have updated the effectiveness of vehicle packages with cooled EGR using the new Ricardo vehicle simulation modeling runs.

Cooled exhaust gas recirculation or Boosted EGR is a combustion concept that involves utilizing EGR as a charge dilutent for controlling combustion temperatures and cooling the EGR prior to its introduction to the combustion system. Higher exhaust gas residual levels at part load conditions reduce pumping losses for increased fuel economy. The additional charge dilution enabled by cooled EGR reduces the incidence of knocking combustion and obviates the need for fuel enrichment at high engine power. This allows for higher boost pressure and/or compression ratio and further reduction in engine displacement and both pumping and friction losses while maintaining performance. Engines of this type use GDI and both dual cam phasing and discrete variable valve lift. The EGR systems considered in this final rule, consistent with the proposal, would use a dual-loop system with both high and low pressure EGR loops and dual EGR coolers. The engines would also use single-stage, variable geometry turbocharging with higher intake boost pressure available across a broader range of engine operation than conventional turbocharged SI engines. Such a system is estimated to be capable of an additional 3 to 5 percent effectiveness relative to a turbocharged, downsized GDI engine without cooled-EGR.[47,48] The agencies have also considered a more advanced version of such a cooled EGR system that employs very high combustion pressures by using dual stage turbocharging. This modeling work has been completed by Ricardo Engineering. The simulation modeling is similar to work that Ricardo conducted for EPA for its 2008 staff report on GHG effectiveness of light-duty vehicle technologies.[49] The agencies have considered this more advanced cooled EGR approach for this final rule, consistent with the proposal.

For the MYs 2012-2016 final rule and TAR, NHTSA and EPA assumed a 5 percent fuel consumption effectiveness for cooled EGR compared to a conventional downsized DI turbocharged engine.[50] Based on the data from the Ricardo and Lotus reports, NHTSA and EPA estimate the incremental reduction in fuel consumption for EGR Boost to be 5 percent over a turbocharged and downsized DI engine. Thus, if cooled EGR is applied to 24-bar engine, adding the 19.3 percent from the turbocharging and downsizing to the 5 percent gain from cooled EGR results in total fuel consumption reduction of 22.1 percent. This is in agreement with the range suggested in the Lotus and Ricardo reports.

In the 2010 TAR, the agencies estimated the DMC of the cooled EGR system at $240 (2007$, see 2010 TAR at page B-12)). This DMC becomes $244 (2010$) for this analysis. This DMC is considered applicable in the 2012MY. The agencies consider cooled EGR technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2024 then 1.29 thereafter. The resultant costs are shown in Table 3-34.

Table 3-34 Costs for Cooled EGR (2010$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025

DMC	All	$212	$208	$204	$199	$195	$192	$188	$184	$180
IC	All	$93	$93	$93	$93	$92	$92	$92	$92	$69
TC	All	$305	$301	$296	$292	$288	$284	$280	$276	$249

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

Note that, in the 2010 TAR, the agencies presented the cooled EGR system costs inclusive of turbo charging costs (see 2010 TAR, Table B2.2-1 at page B-12). For this analysis, the agencies are presenting the cooled EGR costs as a stand-alone technology that can be added to any turbo/downsized engine provided sufficient boost is provided and sufficient engine robustness is accounted for. As such, the cooled EGR system is considered applicable only the 24 bar BMEP and 27 bar BMEP engines. Further, the agencies believe that 24 bar BMEP engines are capable of maintaining NOx control without cooled EGR, so each agency's respective models may choose 24 bar BMEP engines with and/or without cooled EGR. However, as noted above, 27 bar BMEP engines are considered to require cooled EGR to maintain NOx emission control. As such, neither agency's model is allowed to choose 27 bar BMEP technology without also adding cooled EGR.

3.4.1.10 Diesel Engine Technology (DSL)

Diesel engines have several characteristics that give them superior fuel efficiency compared to conventional gasoline, spark-ignited engines. Pumping losses are much lower due to lack of (or greatly reduced) throttling in a diesel engine. The diesel combustion cycle operates at a higher compression ratio than does a gasoline engine. As a result, turbocharged light-duty diesels typically achieve much higher torque levels at lower engine speeds than equivalent-displacement naturally-aspirated gasoline engines. Future high BMEP turbocharged and downsized engines, mentioned above, are projected to improve torque levels at lower engine speeds thus reducing the diesel advantage in this area. Diesels also operate with a very lean air/fuel mixture. These attributes – reduced pumping losses, higher compression ratio and lean/air fuel mixture -- allow the engine to extract more energy from a given mass of fuel than a gasoline engine, and thus make it more efficient. Additionally, diesel fuel has higher energy content per gallon than does gasoline. While diesel fuel has a higher energy content than gasoline, it also contains more carbon per gallon than does gasoline: diesel produces 22.2 pounds of CO_2 per gallon when burned, while gasoline produces 19.4 pounds of CO_2 per gallon. This higher carbon content slightly offsets the GHG emissions benefit of diesel fuel relative to gasoline, however, the disbenefit is more than compensated by the greater efficiency of the diesel engine. Since diesel engines are more fuel efficient than current naturally aspirated PFI gasoline engines, the agencies anticipate that manufacturers will evaluate and potentially invest in diesel engine production as a way to comply with more stringent CAFE standards. However, there are two primary reasons why manufacturers might not choose to invest significantly in diesel engine technologies as a way to comply with the CAFE and GHG standards for MYs 2017-2025.

As discussed above, even though diesel has higher energy content than gasoline it also has a higher carbon density that results in higher amounts of CO_2 emitted per gallon, approximately 15 percent more than a gallon of gasoline. This is commonly referred to as the "carbon penalty" associated with using diesel fuel – a diesel vehicle yields greater fuel economy improvements compared to its CO_2 emissions reduction improvements, so a manufacturer that invests in diesel technology to meet CAFE standards may have more trouble meeting the GHG standards than if it used a different and more cost effective (from a GHG perspective) technology.

And second, diesel engines also have emissions characteristics that present challenges to meeting federal Tier 2 NOx emissions standards. By way of comparison for readers familiar with the European on-road fleet, which contains many more diesel vehicles than the U.S. on-road fleet, U.S. Tier 2 emissions fleet average requirement of bin 5 require roughly 45 to 65 percent more NO_x reduction compared to the Euro VI standards.

Despite considerable advances by manufacturers in developing Tier 2-compliant diesel engines, it remains somewhat of a systems-engineering challenge to maintain the full fuel consumption advantage of the diesel engine while meeting Tier 2 emissions regulations because some of the emissions reduction strategies can *increase* fuel consumption (relative to a Tier 1 compliant diesel engine), depending on the combination of strategies employed. A combination of combustion improvements (that reduce NO_X emissions leaving the engine) and aftertreatment (capturing and reducing NO_X emissions via a NOx adsorption catalyst, or via selective catalytic reduction (SCR) using a reductant such as urea) that have left the engine before they leave the vehicle tailpipe) are being introduced on Tier 2 compliant light-duty diesel vehicles today. However, recently there have been a small number of announcements that diesel engines will be added to some passenger cars, in some cases a segment first for a manufacturer[51], or that new passenger car diesel engines are being designed to meet all global emissions regulations.[52] This suggests to the agencies that some manufacturers may be planning to use diesel engines in their plans to meet the tighter CAFE standards in the mid-term, which may be enabled by advances in diesel engine and emission control technology. Manufacturers that focus on diesel engines have also stated to the agencies their expectation that diesel engines will continue to be a viable technology for improving fuel economy and GHG emissions in the future.

We spend time here discussing available emissions reduction technologies for diesel engines as part of this rulemaking because of the potential they have to impact fuel economy and GHG emissions for the vehicles that have them. With respect to combustion improvements, we note that several key advances in diesel engine combustion technology have made it possible to reduce emissions coming from the engine prior to aftertreatment, which reduces the need for aftertreatment. These technologies include improved fuel systems (higher injection pressure and multiple-injection capability), advanced controls and sensors to optimize combustion and emissions performance, higher EGR levels and EGR cooling to reduce NO_x, and advanced turbocharging systems. These systems are available today and they do not adversely impact fuel efficiency. However, additional improvements in these technologies will be needed to reduce engine emissions further, should future emissions standards become more stringent. Further development may also be needed to reduce the fuel efficiency penalty associated with EGR.

With respect to catalytic exhaust emission control systems, typical 3-way exhaust catalysts without NOx storage capability are not able to reduce NOx emissions from engines operated lean of stoichiometry (diesel or lean-burn gasoline). To reduce NOx, hydrocarbons, and particulate emissions, all diesels will require a catalyzed diesel particulate filter (CDPF) and sometimes a separate diesel oxidation catalyst (DOC), and either a lean NOx trap (LNT) [kk] or the use of a selective catalytic reduction system, typically base-metal zeolite urea-SCR[ll].

The increased cost of diesel emissions control technologies relative to powertrains with stoichiometric gasoline engines that are approaching comparable efficiency may also make diesels less attractive to manufacturers as a technology solution for more stringent CAFE and GHG standards. However, recognizing that some manufacturers may still employ diesel technology to meet the future standards, the agencies have included diesels in our analysis as follows:

The agencies sought to ensure that diesel engines would have equivalent performance to comparable gasoline engine vehicles. For the Subcompact, Compact, and Midsize Passenger Car, Performance Subcompact Car, and Small Light Truck vehicle subclasses, the agencies assumed that an I4 gasoline base engine would be replaced by an in-line 4-cylinder diesel engine with displacement varying around 2.0 liters. For the Performance Compact, Performance Midsize, Large Passenger Car, Minivan, and Midsize Truck vehicle subclasses for the CAFE model, the agencies assumed that a V6 gasoline base engine would be replaced by an in-line 4-cylinder diesel engine with displacement varying around 2.8 liters. For the Large Truck and Performance Large Car vehicle subclasses for the CAFE model, the agencies assumed that a V8 gasoline base engine would be replaced with a V6 diesel engine with displacement varying around 4.0 liters to meet vehicle performance requirements. It was also assumed that diesel engines for all of these classes would utilize SCR aftertreatment systems given recent improvements in zeolite-based SCR systems and system efficiency. These assumptions impacted our estimates of the costs of implementing diesel engines as compared to the base gasoline engines.

[kk] A lean NO_x trap operates by oxidizing NO to NO_2 in the exhaust and storing NO_2 on alkali sorbent material, most often BaO. When the control system determines (via mathematical model and typically a NO_x sensor) that the trap is saturated with NO_x, it switches the engine into a operating mode just rich of stoichiometry that allow NOx to be released from the alkali storage and temporarily allow three-way function of the catalyst similar to three-way catalysts used in stoichiometric gasoline applications. LNTs preferentially store sulfate compounds from the fuel, which reduces NOx storage capacity over time, thus the system must undergo periodic desulfurization by operating at a net-fuel-rich condition at high temperatures in order to retain NO_x trapping efficiency.

[ll] An SCR aftertreatment system uses a reductant (typically, ammonia derived from urea) that is injected into the exhaust stream ahead of the SCR catalyst. Ammonia is a strong reductant even under net lean conditions. It combines with NO_x in the SCR catalyst to form N_2 and water. The hardware configuration for an SCR system is sometimes more complicated than that of an LNT, due to the onboard urea storage and delivery system (which requires a urea pump and injector to inject urea into the exhaust stream), which generally makes an SCR system cost more than an LNT system. While a rich engine-operating mode is not required for NO_x reduction, the urea is typically injected at a rate of approximately 3 percent of the fuel consumed. The agencies understand that manufacturers designing SCR systems intend to align urea tank refills with standard maintenance practices such as oil changes as more diesel vehicles are introduced into the market. For diesel vehicles currently on the market, this is generally already the practice, and represents an ongoing maintenance cost for vehicles with this technology.

Diesel engines are more costly than port-injected spark-ignition gasoline engines. These higher costs result from more costly components, more complex systems for emissions control, and other factors. The vehicle systems that are impacted include:

- Fuel systems (higher pressures and more responsive injectors);
- Controls and sensors to optimize combustion and emissions performance;
- Engine design (higher cylinder pressures require a more robust engine, but higher torque output means diesel engines can have reduced displacement);
- Turbocharger(s);
- Aftertreatment systems, which tend to be more costly for diesels;

In the MYs 2012-2016 final rule, the agencies estimated the DMC for converting a gasoline PFI engine with 3-way catalyst aftertreatment to a diesel engine with diesel aftertreatment at $1,697 (2007$), $2,399 (2007$), $1,956 (2007$) and $2,676 (2007$) for a small car, large car, medium/large MPV & small truck, and large truck, respectively (see final Joint TSD, Table 3-12 at page 3-44). All of these costs were for SCR-based diesel systems, with the exception of the small car, which was a LNT-based system. For this final rule, consistent with the proposal, we are using the same methodology as used in the MYs 2012-2016 final rule, but have made four primary changes to the cost estimates as was also done in the proposal for this rule. First, the agencies have not estimated costs for a LNT-based system, and instead have estimated costs for all vehicle types assuming they will employ SCR-based systems. Second, the agencies assumed that manufacturers would meet a Tier 2 bin 2 average rather than a Tier 2 bin 5 average, assuming that more stringent levels of compliance will be required in the future. In order to estimate costs for Tier 2 bin 2 compliant vehicles, catalyst volume costs were estimated based on an assumed increase in volume of 20 percent. This was the estimated necessary increase needed to meet Tier 2, bin 2 emission level of 0.02 grams of NOx per mile. Increased catalyst volume resulted in a higher cost estimate for diesel aftertreatment than was estimated for the MYs 2012-2016 final rule. The third is to update all platinum group metal costs from the March 2009 values used in the 2012-2016 final rule to February 2011 values.[mm] The February 2011 values were used for purposes of the NPRM analysis, at which time they represented the most recent monthly average prices available at the time the agencies "locked-down" all cost estimates for the purposes of moving into the modeling phase of analysis.[nn] For the final rule analysis, the

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[mm] As reported by Johnson-Matthey, the March 2009 monthly average costs were $1,085 per Troy ounce and $1,169 per Troy ounce for platinum (Pt) and rhodium (Rh), respectively. As also reported by Johnson-Matthey, the February 2011 monthly average costs were $1,829 per Troy ounce and $2,476 per Troy ounce for Pt and Rh, respectively. See www.platinum.matthey.com.

[nn] Note that there is no good way of determining what PGM prices to use when conducting cost analyses. Spot prices are inherently dangerous to use because spot prices, like stock prices on the stock market, can vary considerably from day to day. One could argue that an average price is best, but average prices can vary considerably depending on the length of time included in the average. And if too much time is included in the average, then average prices from a time prior to PGM use in diesel engines may be included which would lead some to conclude that we had cherry picked our values. Given no good option, it seems most transparent and

agencies did not update the cost for platinum group metals. The fourth is to include an additional $50 DMC for all costs to cover costs associated with improvements to fuel and urea controls. All of the diesel costs are considered applicable to MY 2012. The agencies consider diesel technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2018, and then an ICM of 1.29 thereafter. The resultant costs are shown in Table 3-35.

Table 3-35 Costs for Conversion to Advanced Diesel (2010$)

Cost type	Vehicle class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	$2,059	$2,018	$1,978	$1,938	$1,900	$1,862	$1,824	$1,788	$1,752
DMC	Standard car	$2,059	$2,018	$1,978	$1,938	$1,900	$1,862	$1,824	$1,788	$1,752
DMC	Large car	$2,522	$2,472	$2,422	$2,374	$2,326	$2,280	$2,234	$2,190	$2,146
DMC	Small MPV	$2,064	$2,023	$1,982	$1,943	$1,904	$1,866	$1,828	$1,792	$1,756
DMC	Large MPV	$2,082	$2,040	$1,999	$1,959	$1,920	$1,882	$1,844	$1,807	$1,771
DMC	Large truck	$2,886	$2,828	$2,772	$2,716	$2,662	$2,609	$2,556	$2,505	$2,455
IC	Small car	$905	$903	$675	$674	$673	$672	$671	$669	$668
IC	Standard car	$905	$903	$675	$674	$673	$672	$671	$669	$668
IC	Large car	$1,109	$1,106	$827	$826	$824	$823	$821	$820	$819
IC	Small MPV	$907	$905	$677	$676	$674	$673	$672	$671	$670
IC	Large MPV	$915	$913	$683	$681	$680	$679	$678	$677	$676
IC	Large truck	$1,268	$1,266	$946	$945	$943	$941	$940	$938	$937
TC	Small car	$2,965	$2,922	$2,653	$2,612	$2,572	$2,533	$2,495	$2,457	$2,420
TC	Standard car	$2,965	$2,922	$2,653	$2,612	$2,572	$2,533	$2,495	$2,457	$2,420
TC	Large car	$3,631	$3,578	$3,249	$3,200	$3,151	$3,103	$3,056	$3,010	$2,964
TC	Small MPV	$2,971	$2,928	$2,659	$2,618	$2,578	$2,539	$2,501	$2,463	$2,426
TC	Large MPV	$2,996	$2,953	$2,682	$2,641	$2,600	$2,561	$2,522	$2,484	$2,446
TC	Large truck	$4,154	$4,094	$3,718	$3,661	$3,605	$3,550	$3,496	$3,443	$3,392

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

For the MYs 2012-16 final rule and TAR, NHTSA and EPA estimated the fuel consumption reduction of a SCR-based diesel engine to be between 20 to 25 percent over a baseline gasoline engine. NHTSA and EPA have revisited these values and have now estimated, based on the Ricardo 2011 study, the effectiveness of a SCR-based diesel engine to be 28.4 to 30.5 percent. For purposes of CO_2 reduction, EPA estimates a 7 to 20 percent for light-duty diesels equipped with SCR.

3.4.2 Transmission Technologies

NHTSA and EPA have also reviewed the transmission technology estimates used in the 2012-2016 final rule and the 2010 TAR. In doing so, NHTSA and EPA considered or reconsidered all available sources and updated the estimates as appropriate. The section below describes each of the transmission technologies considered for this rulemaking. As discussed above, for the final rule NHTSA has updated the effectiveness values for advanced transmissions when coupled to naturally-aspirated engines based on the ANL simulation

least self-serving to simply choose a price and report its basis. In the end, the PGM costs represent 16-23 percent of the diesel DMC in this analysis. Further, diesels play very little to no role in enabling compliance with the final standards.

modeling. These changes are documented in detail in NHTSA's RIA. These changes are not included in this joint TSD because they are specific to NHTSA's analysis only.

3.4.2.1 Improved Automatic Transmission Control (Aggressive Shift Logic and Early Torque Converter Lockup)

Calibrating the transmission shift schedule to upshift earlier and quicker, and to lock-up or partially lock-up the torque converter under a broader range of operating conditions can reduce fuel consumption and CO_2 emissions. However, this operation can result in a perceptible degradation in noise, vibration, and harshness (NVH). The degree to which NVH can be degraded before it becomes noticeable to the driver is strongly influenced by characteristics of the vehicle, and although it is somewhat subjective, it always places a limit on how much fuel consumption can be improved by transmission control changes. Aggressive Shift Logic and Early Torque Converter Lockup are best optimized simultaneously when added to an automatic transmission due to the fact that adding both of them requires only minor modifications to the transmission mechanical components or calibration software. As a result, these two technologies are combined in the modeling when added to an automatic transmission. Since a dual clutch transmission (DCT) has no torque converter, the early torque converter lockup technology is not included when adding ASL to the DCT.

3.4.2.2 Aggressive Shift Logic

During operation, a transmission's controller manages the operation of the transmission by scheduling the upshift or downshift, and, in automatic transmissions, locking or allowing the torque converter to slip based on a preprogrammed shift schedule. The shift schedule contains a number of lookup table functions, which define the shift points and torque converter lockup based on vehicle speed and throttle position, and other parameters such as temperature. Aggressive shift logic (ASL) can be employed in such a way as to maximize fuel efficiency by modifying the shift schedule to upshift earlier and inhibit downshifts under some conditions, which reduces engine pumping losses and engine friction. The application of this technology does require a manufacturer to confirm that drivability, durability, and NVH are not significantly degraded.

For this final rule, consistent with the proposal, the agencies considered two levels of ASL. The first level is that discussed in the 2012-2016 final rule and the 2010 TAR. ASL-level 1 is an early upshift strategy whereby the transmission shifts to the next higher gear "earlier" (or at lower RPM during a gradual acceleration) than would occur in a traditional automatic transmission. This early upshift reduces fuel consumption by allowing the engine to operate at a lower RPM and higher load, which typically moves the engine into a more efficient operating region.

ASL-level 2 is a shift optimization strategy whereby the engine and/or transmission controller(s) continuously evaluate all possible gear options that would provide the necessary tractive power (while limiting the adverse effects on driveline NVH) and select the gear that lets the engine run in the most efficient operating zone. Ricardo acknowledged in its report that the ASL-level 2 ("shift optimization") strategy currently causes significant implications for drivability and hence affects consumer acceptability. However, Ricardo recommended the inclusion of this technology for the 2020-2025 timeframe with the assumption that manufacturers will develop a means of yielding the fuel economy benefit without adversely affecting driver acceptability. The agencies believe these drivability challenges could include shift busyness – that is, a high level of shifting compared to current vehicles as perceived by the customers. The agencies note that in confidential discussions with two major transmission suppliers, the suppliers described transmission advances which reduce shifting time and provide smoother torque transitions than today's designs, making the shifting event less apparent to the driver, however these improvements will not influence the customer's perception of shift business related to the changes in engine speed.

In addition, the agencies note that several auto companies and transmission firms have announced future introduction of transmissions into the U.S. market with even a higher number of gears than were included in the Ricardo simulation and in the agencies' feasibility assessment for this final rule, consistent with the proposal (which is 8 forward speeds). These announcements include both 9 and 10 speed transmissions which may present further challenges with shift busyness, given the availability of one or two additional gears. At the same time, the associated closer gear spacing will generally result in smaller engine speed changes during shifting that may be less noticeable to the driver.

The agencies are including shift optimization in the analysis under the premise that manufacturers and suppliers are developing means to mitigate these drivability issues by MY 2017, as assumed in the 2011 Ricardo study (more information on Ricardo's treatment of the optimized shift strategy is described in Section 6.4 of the 2011 Ricardo report). If manufacturers are not able to solve these drivability issues, the assumed effectiveness could be lower and the cost could be higher or both. The agencies sought comment on the feasibility of ASL-level 2 and the likelihood that manufacturers will be able to overcome the drivability issues, however no comments were submitted on this issue.

In MYs 2012-2016 final rule, the agencies estimated an effectiveness improvement of 1 to 2 percent for aggressive shift logic which was supported by the 2002 NAS and NESCCAF reports as well as confidential manufacturer data. The agencies updated the effectiveness of ASL-level 1 ranging from 1.9 to 2.7 based on 2010 Ricardo study. In CAFE model an incremental effectiveness ranging for both ASL and early torque converter lockup ranging from 2.3 to 3.1 percent is applied (Early torque converter has effectiveness of 0.5 percent).

ASL-level 2 is new to this analysis which is based on the shift optimization algorithm in 2011 Ricardo study. The effectiveness for ASL-level 2 ranges from 5.1 to 7.0 percent improvement over transmission with unimproved shift logic or roughly 4 to 5 percent over a transmission that already incorporates aggressive shift logic. In the CAFE model, an incremental effectiveness ranging from 3.27 to 4.31 percent is applied.

In the 2012-2016 rule, the agencies estimated the DMC at $26 (2007$) which was considered applicable to the 2015MY. This DMC becomes $27 (2010$) for this analysis. The agencies consider ASL-level 1 technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2018 then 1.29 thereafter. For

ASL-level 2, the agencies are estimating the DMC at an equivalent $27 (2010$) except that this cost is considered applicable to the 2017MY. Essentially this yields a nearly negligible incremental cost for ASL-level 2 over ASL-level 1. The agencies consider ASL-level 2 technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2024 then 1.29 thereafter. The timing of the ASL-level 2 ICMs is different than that for the level 1 technology because the level 2 technology is newer and not yet being implemented in the fleet. The resultant costs are shown in Table 3-36. Note that both levels of ASL technology are incremental to the baseline system, so ASL-level 2 is not incremental to ASL-level 1.

Table 3-36 Costs for Aggressive Shift Logic Levels 1 & 2 (2010$)

Cost type	Technology	Transmission type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	ASL-level 1	All	$26	$26	$25	$24	$24	$24	$23	$23	$22
DMC	ASL-level 2	All	$27	$27	$26	$25	$24	$24	$23	$23	$22
IC	ASL-level 1	All	$7	$7	$5	$5	$5	$5	$5	$5	$5
IC	ASL-level 2	All	$7	$7	$7	$7	$7	$7	$7	$7	$5
TC	ASL-level 1	All	$33	$32	$30	$30	$29	$29	$28	$28	$27
TC	ASL-level 2	All	$34	$33	$32	$32	$31	$30	$30	$29	$27

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

3.4.2.3 Early Torque Converter Lockup

A torque converter is a fluid coupling located between the engine and transmission in vehicles with automatic transmissions and continuously-variable transmissions (CVT). This fluid coupling allows for slip so the engine can run while the vehicle is idling in gear (as at a stop light), provides for smoothness of the powertrain, and also provides for torque multiplication during acceleration, and especially launch. During light acceleration and cruising, the inherent slip in a torque converter causes increased fuel consumption, so modern automatic transmissions utilize a clutch in the torque converter to lock it and prevent this slippage. Fuel consumption can be further reduced by locking up the torque converter at lower vehicle speeds, provided there is sufficient power to propel the vehicle, and noise and vibration are not excessive.[oo] If the torque converter cannot be fully locked up for maximum efficiency, a partial lockup strategy can be employed to reduce slippage. Early torque converter lockup is applicable to all vehicle types with automatic transmissions. Some torque converters will require upgraded clutch materials to withstand additional loading and the slipping conditions during partial lock-up. As with aggressive shift logic, confirmation of acceptable drivability, performance, durability and NVH characteristics is required to successfully implement this technology.

[oo] Although only modifications to the transmission calibration software are considered as part of this technology, very aggressive early torque converter lock up may require an adjustment to damper stiffness and hysteresis inside the torque converter.

Regarding the effectiveness of Early Torque Converter Lockup, the 2012-2016 final rule, TAR, and the 2010 Ricardo study estimated an effectiveness improvement of 0.4 to 0.5 percent.

In the 2012-2016 rule, the agencies estimated the DMC at $24 (2007$) which was considered applicable to the 2015MY. This DMC remains $25 (2010$) for this analysis.[pp] The agencies consider early torque converter lockup technology to be on the flat portion of the learning curve and have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. The resultant costs are shown in Table 3-37.

Table 3-37 Costs for Early Torque Converter Lockup (2010$)

Cost type	Transmission type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Automatic	$24	$23	$23	$22	$22	$21	$21	$20	$20
IC	Automatic	$6	$6	$5	$5	$5	$5	$5	$5	$5
TC	Automatic	$30	$29	$27	$27	$27	$26	$26	$25	$25

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

3.4.2.4 High Efficiency Gearbox

For this rule, a high efficiency gearbox refers to some or all of a suite of incremental gearbox improvement technologies that should be available within the 2017 to 2025 timeframe. The majority of these improvements address mechanical friction within the gearbox. These improvements include but are not limited to: shifting clutch technology improvements (especially for smaller vehicle classes), improved kinematic design, dry sump lubrication systems, more efficient seals, bearings and clutches (reducing drag), component superfinishing and improved transmission lubricants. More detailed description can be found in the 2011 Ricardo report[53]. Note that the high efficiency gearbox technology is applicable to any type of transmission.

EPA analyzed detailed transmission efficiency input data provided by Ricardo and implemented it directly into the lumped parameter model. Based on the LP effectiveness resulting from these inputs, EPA and NHTSA estimate that a high efficiency gearbox can provide a GHG or fuel consumption reduction in the range of 3.8 to 5.7 percent (3.8% for 4WD trucks with an unimproved rear axle) over a baseline automatic transmission in MY2017 and beyond.

The agencies estimate the DMC of the high efficiency gearbox at $200 (2009$). We have based this on the DMC for engine friction reduction in a V8 engine which, as presented in Table 3-24 is $197 (2010$). In the proposal, we rounded this value up to $200 (2009$)

[pp] As is true throughout this presentation of cost estimates, the agencies round costs to the nearest dollar. In the actual model input files, the cost in 2007$ would have been $23.68 and the cost in 2009$ is $24.42. So an impact of the dollar-year conversion is reflected in the analysis even when it does not appear so in this presentation.

which becomes $202 (2010$) for the final analysis. This DMC is considered applicable for the 2017MY. The agencies consider high efficiency gearbox technology to be on the flat portion of the learning curve and have applied a low complexity ICM of 1.24 through 2024 then 1.19 thereafter. The resultant costs are shown in Table 3-38.

Table 3-38 Costs for High Efficiency Gearbox (2010$)

Cost type	Transmission type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Automatic/Dual clutch	$202	$196	$190	$184	$179	$173	$170	$167	$163
IC	Automatic/Dual clutch	$49	$49	$49	$49	$49	$49	$48	$48	$39
TC	Automatic/Dual clutch	$251	$245	$239	$233	$227	$222	$218	$215	$202

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

3.4.2.5 Automatic 6-, 7- and 8-Speed Transmissions (NAUTO and 8SPD)

Manufacturers can also choose to replace 4- and 5-speed transmission with 6-, 7-, or 8-speed automatic transmissions. Additional ratios allow for further optimization of engine operation over a wider range of conditions, but this is subject to diminishing returns as the number of speeds increases. As additional planetary gear sets are added (which may be necessary in some cases to achieve the higher number of ratios), additional weight and friction are introduced. Also, the additional shifting of such a transmission can be perceived as bothersome to some consumers, so manufacturers need to develop strategies for smooth shifts. Some manufacturers are replacing 4- and 5-speed automatics with 6-speed automatics, and 7- and 8-speed automatics have also entered production. While a six speed transmission application was most prevalent for the 2012-2016 final rule, eight speed transmissions are expected to be readily available and applied in the 2017 through 2025 timeframe.

As discussed in the MY 2011 CAFE final rule, confidential manufacturer data projected that 6-speed transmissions could incrementally reduce fuel consumption by 0 to 5 percent from a baseline 4-speed automatic transmission, while an 8-speed transmission could incrementally reduce fuel consumption by up to 6 percent from a baseline 4-speed automatic transmission. GM has publicly claimed a fuel economy improvement of up to 4 percent for its new 6-speed automatic transmissions.[54] The 2008 EPA Staff Technical Report found a 4.5 to 6.5 percent fuel consumption improvement for a 6-speed over a 4-speed automatic transmission.[55] Based on this information, NHTSA estimated in the MY 2011 rule, that the conversion to a 6-,7- and 8-speed transmission (NAUTO) from a 4 or 5-speed automatic transmission with IATC would have an incremental fuel consumption benefit of 1.4 percent to 3.4 percent, for all vehicle classes. From a baseline 4 or 5 speed transmission without IATC, the incremental fuel consumption benefit would be approximately 3 to 6 percent, which is consistent with the EPA Staff Report estimate. In MYs 2012-2016 final rule, NHTSA and EPA reviewed these effectiveness estimates and concluded that they remain accurate. While the CAFE model follows the incremental approach discussed above, the GHG model estimates the packaged effectiveness of 4.5 to 6.5 percent

In this FRM analysis, consistent with the proposal, the agencies divided the improvement for this technology into two steps, first from 4 or 5 speed transmission to 6 or 7 speed transmission (NAUTO), then from 6 or 7 speed transmission to 8 speed transmission (8SPD). The effectiveness estimates for NAUTO and 8SPD are based on 2011 Ricardo study. In this FRM analysis, consistent with the proposal, the effectiveness for a 6-speed transmission relative to a 4-speed base transmission ranges from 3.1 to 3.9 percent (2.1 percent for large truck with unimproved rear axle) including 7 percent of transmission gearbox efficiency improvement that the agencies assumed accompanying the new 6 speed transmission after MY 2010. NHTSA incorporated this effectiveness estimate into the CAFE model as incremental improvement over IATC ranging from 1.89 to 2.13 percent. In this FRM analysis, consistent with the proposal, the agencies assumed that 8-speed transmission will not start to phase in until MY2017. NHTSA applied 8-speed automatic transmission succeeding 6-speed automatic transmission to vehicles with towing requirement, such as Minivan, Midsize light truck and large light truck. All other vehicle subclasses use 8-speed DCT to succeed 6-speed DCT. The effectiveness for an 8-speed DCT relative to a 4-speed DCT transmission ranges from 11.1 to 13.1 percent for subcompact car, small car and small light truck. The effectiveness for an 8-speed automatic transmission relative to 4-speed automatic transmission ranges for large CUV and large truck ranges from 8.7 to 9.2 percent in the lumped parameter model. This translates into effectiveness in the range of 3.85 to 4.57 percent for an 8-speed DCT relative to a 6-speed DCT and 4.9 to 5.34 percent for 8-speed automatic transmission relative to 6-speed automatic transmission in CAFE model.

In the 2010 TAR, the agencies estimated the DMC at -$13 (2008$) for a 6 speed automatic transmission relative to a 4 speed auto transmission, applicable in the 2017MY (see 2010 TAR, Table B2.1-1 at page B-10). For the 2012MY, that DMC was -$15 (2008$), although that value was not presented in the TAR. The latter DMC remains -$15 (2010$) for this analysis which is considered to be applicable in the 2012MY. The agencies consider 6 speed automatic transmission technology to be on the flat portion of the learning curve and have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. The resultant costs are shown in Table 3-39.

New for the proposal was the cost of an 8 speed automatic transmission. For the cost of this technology, the agencies have relied on a tear-down study completed by FEV since publication of the TAR.[56] In that study, the 8 speed auto transmission was found to be $62 (2007$) more costly than the 6 speed auto transmission. This DMC becomes $64 (2010$) for this analysis. Adding the $64 (2010$) to the -$15 (2010$) DMC for a 6 speed relative to a 4 speed, the 8 speed auto transmission relative to a 4 speed auto transmission would be $50 (2010$). The agencies consider this DMC to be applicable to the 2012MY. The agencies consider the 8 speed auto transmission technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through the 2018MY then 1.29

thereafter.[qq] The resultant costs for both 6 speed and 8 speed auto transmissions are shown in Table 3-39.

Table 3-39 Costs for 6 and 8 Speed Automatic Transmissions (2010$)

Cost type	Transmission type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	6spAT from 4spAT	-$13	-$13	-$12	-$12	-$12	-$12	-$11	-$11	-$11
DMC	8spAT from 6spAT	$56	$55	$54	$53	$51	$50	$49	$48	$47
DMC	8spAT from 4spAT	$43	$42	$41	$40	$40	$39	$38	$37	$37
IC	6spAT from 4spAT	$4	$4	$3	$3	$3	$3	$3	$3	$3
IC	8spAT from 6spAT	$25	$24	$18	$18	$18	$18	$18	$18	$18
IC	8spAT from 4spAT	$19	$19	$14	$14	$14	$14	$14	$14	$14
TC	6spAT from 4spAT	-$9	-$9	-$10	-$9	-$9	-$9	-$9	-$8	-$8
TC	8spAT from 6spAT	$80	$79	$72	$71	$70	$69	$68	$67	$66
TC	8spAT from 4spAT	$62	$61	$55	$54	$54	$53	$52	$51	$50

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; sp=speed; AT=automatic transmission

Note that the cost for the 8 speed automatic transmission relative to the 6 speed automatic transmission is lower here than that used in the recent heavy-duty GHG rule. In that rule, we remained consistent with the proposal for that rule which carried an estimated DMC of $210 (2008$). That DMC was based on an estimate derived by NAS (see NAS 2010, Table 7-10). For this final rule, consistent with the proposal, we have chosen to use the more recent DMC shown in Table 3-39 which is based on a tear-down analysis done by FEV.

3.4.2.6 Dual Clutch Transmissions / Automated Manual Transmissions (DCTAM)

An Automated Manual Transmission (AMT) is mechanically similar to a conventional manual transmission, but shifting and launch functions are automatically controlled by the electronics. There are two basic types of AMTs, single-clutch and dual-clutch (DCT). A single-clutch AMT is essentially a manual transmission with automated clutch and shifting. Because of shift quality issues with single-clutch designs, DCTs are far more common in the U.S. and are the basis of the estimates that follow. A DCT uses separate clutches (and separate gear shafts) for the even-numbered gears and odd-numbered gears. In this way, the next expected gear is pre-selected, which allows for faster and smoother shifting. For example, if the vehicle is accelerating in third gear, the shaft with gears one, three and five has gear three engaged and is transmitting power. The shaft with gears two, four, and six is idle, but has gear four engaged. When a shift is required, the controller disengages the odd-gear clutch while simultaneously engaging the even-gear clutch, thus making a smooth shift. If, on the other hand, the driver slows down instead of continuing to accelerate, the transmission will have to change to second gear on the idling shaft to anticipate a downshift. This shift can be made quickly on the idling shaft since there is no torque being transferred on it.

[qq] This ICM would be applied to the 6 speed to 8 speed increment of $64 (2010$) applicable in 2012. The 4 speed to 6 speed increment would carry the low complexity ICM.

In addition to single-clutch and dual-clutch AMTs, there are also wet clutch and dry clutch designs which are used for different types of vehicle applications. Wet clutch AMTs offer a higher torque capacity that comes from the use of a hydraulic system that cools the clutches. Wet clutch systems are less efficient than the dry clutch systems due to the losses associated with hydraulic pumping. Additionally, wet AMTs have a higher cost due to the additional hydraulic hardware required.

Overall, DCTs likely offer the greatest potential for effectiveness improvements among the various transmission options presented in this report because they offer the inherently lower losses of a manual transmission with the efficiency and shift quality advantages of electronic controls. The lower losses stem from the elimination of the conventional lock-up torque converter, and a greatly reduced need for high pressure hydraulic circuits to hold clutches or bands to maintain gear ratios (in automatic transmissions) or hold pulleys in position to maintain gear ratio (in Continuously Variable Transmissions). However, the lack of a torque converter will affect how the vehicle launches from rest, so a DCT will most likely be paired with an engine that offers sufficient torque at low engine speeds to allow for adequate launch performance or provide lower launch gears to approximate the torque multiplication of the torque converter to provide equivalent performance.

In MYs 2012-2016 final rule, EPA and NHTSA estimated a 5.5 to 9.5 percent improvement in fuel consumption over a baseline 4/5-speed automatic transmission for a wet clutch DCT, which was assumed for all but the smallest of vehicle subclasses, Subcompact and Compact cars and small LT. This results in an incremental effectiveness estimate of 2.7 to 4.1 percent over a 6-speed automatic transmission with IATC. For Subcompact and Compact Cars and small LT, which were assumed to use a dry clutch DCT, NHTSA estimated an 8 to 13 percent fuel consumption improvement over a baseline 4/5-speed automatic transmission, which equates to a 5.5 to 7.5 percent incremental improvement over the 6-speed transmission.

Based on the 2011 Ricardo study, EPA and NHTSA have concluded that 8 to 13 percent effectiveness is appropriate for 6-speed DCTs and 11 to 16 percent is appropriate for 8-speed DCTs for this final rule, consistent with the proposal. These values include not only the DCT but also the increase in stepped gears and also a high efficiency gearbox (mentioned later). Independent of other technologies, this translates to an effectiveness for the DCT, alone, of 4 to 5% (for wet-clutch designs) and 5 to 6% (for dry-clutch designs) compared to a baseline automatic transmission of similar vintage and number of fixed gears.

In this FRM analysis, consistent with the proposal, NHTSA applied an incremental effectiveness of 4 percent for a 6-speed dry DCT and 3.4 to 3.8 percent for a wet DCT compared to a 6-speed automatic transmission based on the lumped parameter model which includes the accompanied transmission efficiency improvement for MY 2010 and after transmissions. This translates to an effectiveness range of 7.4 to 8.6 percent compared to a 4 speed automatic transmission for dry clutch design and 7.4 to 7.9 percent for a wet clutch design. NHTSA did not apply DCTs to vehicles with towing requirements, such as Minivan, Midsize light truck and large pickup truck. EPA did not apply DCTs to vehicle types classified as towing as described in Chapter 1 of EPA's RIA.

In the 2010 TAR, the agencies estimated the DMC at -$234 (2008$) for a 6 speed dry-clutch DCT and -$165 for a 6 speed wet-clutch DCT with both DMCs applicable in the 2017MY (see 2010 TAR, Table B2.1-1 at page B-10) and both incremental to a 4 speed automatic transmission. In the 2010 TAR, we pointed to Chapter 3 of the 2012-2016 final joint TSD where we noted that the DCT costs of -$147 (2007$ and incremental to a 6-speed automatic transmission) were based on a FEV tear-down study that assumed 450,000 units of production. We went on to state that we did not consider there to be sufficient US capacity in the 2012-2016 timeframe to produce 450,000 units and for that reason we were adjusting the tear-down values accordingly. The TAR timeframe for consideration was 2017-2025, and in the TAR we argued that production capacity would exist and that the FEV tear-down results be valid without adjustment. As noted in the proposal to this rule, we continue to believe that to be the case. In the final joint TSD supporting the 2012-2016 rule we also noted that the negative tear-down estimates found by FEV were not surprising when considering the relative simplicity of a dual-clutch transmission compared to an automatic transmission. Again, we continue to consider this to be true.

For this analysis, we consider the 2010 TAR DMCs to be applicable to the 2012MY, thus the DMCs become -$238 (2010$) and -$168 (2010$) for 6 speed dry- and wet-clutch DCTs, respectively, both applicable in the 2012MY and incremental to a 4 speed auto transmission. The agencies consider the 6 speed DCT technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2018 then 1.29 thereafter. The resultant costs are shown in Table 3-40.

New for this rulemaking is costing for an 8 speed DCT. For the cost of this technology, the agencies have relied on a tear-down study completed by FEV since publication of the TAR.[57] In that study, the 8 speed DCT was found to be $198 (2007$) more costly than the 6 speed DCT. This DMC increment becomes $206 (2010$) for this analysis. Adding the $206 (2010$) to the -$238 (2010$) DMC and the -$168 (2010$) DMC for a 6 speed dry- and wet-clutch DCT, the 8 speed dry- and wet-clutch DCTs relative to a 4 speed auto transmission would be -$32 (2010$) and $38 (2010$), respectively. The agencies consider this DMC to be applicable to the 2012MY. The agencies consider the 8 speed DCT technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through the 2024MY then 1.29 thereafter. The 8 speed DCT has a later switch to long term ICMs because it is a newer technology that is not currently implemented in the fleet. The resultant costs for both 6 speed and 8 speed DCTs are shown in Table 3-40.

Table 3-40 Costs for 6 & 8 Speed Dual Clutch Transmissions (2010$)

Cost type	Transmission type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	6spDCT-dry	-$207	-$203	-$199	-$195	-$191	-$187	-$183	-$179	-$176
DMC	6sp DCT-wet	-$146	-$143	-$140	-$137	-$134	-$132	-$129	-$127	-$124
DMC	8sp DCT-dry	-$28	-$27	-$27	-$26	-$26	-$25	-$25	-$24	-$24
DMC	8sp DCT-wet	$33	$32	$32	$31	$30	$30	$29	$29	$28
IC	6spDCT-dry	$91	$91	$68	$68	$68	$67	$67	$67	$67
IC	6sp DCT-wet	$64	$64	$48	$48	$48	$48	$47	$47	$47
IC	8sp DCT-dry	$12	$12	$12	$12	$12	$12	$12	$12	$9
IC	8sp DCT-wet	$14	$14	$14	$14	$14	$14	$14	$14	$11

TC	6spDCT-dry	-$116	-$112	-$131	-$127	-$123	-$119	-$116	-$112	-$109
TC	6sp DCT-wet	-$82	-$79	-$92	-$89	-$87	-$84	-$82	-$79	-$77
TC	8sp DCT-dry	-$16	-$15	-$15	-$14	-$14	-$13	-$13	-$12	-$15
TC	8sp DCT-wet	$47	$47	$46	$45	$45	$44	$44	$43	$39

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; sp=speed; dry=dry clutch; wet=wet-clutch
Note that all costs are relative to a 4 speed automatic transmission.

3.4.2.7 6-Speed Manual Transmissions (6MAN)

Manual transmissions are entirely dependent upon driver input to shift gears: the driver selects when to perform the shift and which gear to select. This is the most efficient transfer of energy of all transmission layouts, because it has the lowest internal gear losses, with a minimal hydraulic system, and the driver provides the energy to actuate the clutch. From a systems viewpoint, however, vehicles with manual transmissions have the drawback that the driver may not always select the optimum gear ratio for fuel economy. Nonetheless, increasing the number of available ratios in a manual transmission can improve fuel economy by allowing the driver to select a ratio that optimizes engine operation more often. Typically, this is achieved through adding overdrive ratios to reduce engine speed at cruising velocities (which saves fuel through reduced engine pumping losses) and pushing the torque required of the engine towards the optimum level. However, if the gear ratio steps are not properly designed, this may require the driver to change gears more often in city driving, resulting in customer dissatisfaction. Additionally, if gear ratios are selected to achieve improved launch performance instead of to improve fuel economy, then no fuel saving effectiveness is realized.

The 2012-2016 final rule estimated an effectiveness increase of 0.5 percent for replacing a 5-speed manual with a 6-speed manual transmission, which was derived from confidential manufacturer data Based on the updated LPM for this 2017-2025 rule, NHTSA has found that an effectiveness increase of 2.0 to 2.5 percent is possible when moving from a 5-speed to a 6-speed manual transmission with improved internals. NHTSA updated costs from the 2012-2016 final rule to reflect the ICM low complexity markup of 1.11 which resulted in an incremental compliance cost of $250 as compared to $338 for MY 2012. This represents a DMC of $225 (2007$) which becomes $234 (2010$) for this analysis, applicable in the 2012MY. NHTSA continues to consider a 6 speed manual transmission to be on the flat portion of the learning curve and has applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. NHTSA's resultant costs for a 6 speed manual transmission are shown in Table 3-41.

Table 3-41 Costs for 6 Speed Manual Transmission (2010$)

Cost type	Transmission type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	6sp manual	$204	$199	$196	$192	$188	$184	$181	$177	$173
IC	6sp manual	$57	$57	$45	$44	$44	$44	$44	$44	$44
TC	6sp manual	$260	$256	$240	$236	$232	$229	$225	$221	$218

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; sp=speed; dry=dry clutch; wet=wet-clutch
Note that all costs are relative to a 5 speed manual transmission.

3.4.3 Vehicle electrification and hybrid electric vehicle technologies

For the costs presented in this electrification and hybrid vehicle section, we have estimated costs for vehicle classes since the technologies are closely linked to the size of the vehicle as opposed to the number of cylinders on the engine or its valvetrain configuration. The vehicle classes for which we have estimated costs are consistent with the six vehicle classes developed for the lumped parameter model. Each agency has used the vehicle class specific costs and mapped those into their respective model-specific vehicle classes or types as shown in Table 3-42. This table simply presents the mapping of lumped parameter model vehicle classes (or cost vehicle classes) into model-specific vehicle classes (or vehicle types in the case of EPA's OMEGA model, please refer to Chapter 1 of EPA's final RIA for more details) to help the reader understand how the vehicle classes used for costing relate to the vehicle classes used for modeling. Note that there have been changes in the EPA data since the proposal. EPA now characterizes cost vehicle classes more consistently with the way they are classified in the lumped parameter model to avoid any confusion that the proposed cost vehicle classes may have generated. EPA has also reconfigured its 19 vehicle types in an effort to more closely align the vehicle types with the actual vehicles contained in each. Both of these changes are detailed in Chapter 1 of EPA's final RIA.

Table 3-42 Mapping of Vehicle Class into each Agency's Model-Specific Vehicle Classes or Types

EPA Vehicle Class for Cost Purpose	Lumped Parameter Classification	Example	OMEGA Model Vehicle Type*	NHTSA/CAFE Model Classification
Subcompact/ Small Car	Small Car	Fiesta Focus Yaris	1	Subcompact Subcompact Perf PC Compact Compact Perf PC
Standard Car	Standard Car	Fusion Taurus Camry	2, 3, 4	Mid-size PC Mid-size Perf PC
Large Car	Large Car	Crown Victoria Mustang	5, 6	Large PC Large Perf PC
Small MPV	Small MPV	Escape Rav4 Tacoma	7, 13	Small LT
Large MPV	Large MPV	Edge Explorer 4Runner Sienna	8, 9, 10, 14, 15	Midsize LT Minivan LT
Truck	Truck	F150 Tundra	11, 12, 16, 17, 18, 19	Large LT

* OMEGA uses 19 vehicle types as shown here and described in detail in Chapter 1 of EPA's final RIA.

3.4.3.1 Electrical Power Steering (EPS) / Electrohydraulic Power Steering (EHPS)

Electric power steering (EPS) and Electrohydraulic power steering (EHPS) provide a potential reduction in CO_2 emissions and fuel consumption over hydraulic power steering because of reduced overall accessory loads. This eliminates the parasitic losses associated with belt-driven power steering pumps which consistently draw load from the engine to pump hydraulic fluid through the steering actuation systems even when the wheels are not being turned. EPS is an enabler for all vehicle hybridization technologies since it provides power steering when the engine is off. EPS may be implemented on most vehicles with a standard 12V system. Some heavier vehicles may require a higher voltage system or EHPS which may add cost and complexity.

The 2012-2016 final rule, EPA and NHTSA estimated a 1 to 2 percent effectiveness for light duty vehicles based on the 2002 NAS report, Sierra Research Report and confidential OEM data. The 2010 Ricardo study also confirmed this estimate. NHTSA and EPA reviewed these effectiveness estimates and found them to be accurate, thus they have been retained for this final rule, consistent with the proposal. For large pickup truck the agencies used EHPS due to the utility requirement of these vehicles. The effectiveness of EHPS is estimated to be 0.8 percent.

In the MY 2012-2016 final rule, the agencies estimated the DMC at $88 (2007$). Converting to 2010$, this DMC becomes $92 for this analysis, consistent with the recent heavy-duty GHG rule, which is considered applicable in the 2015MY. The agencies use the same DMC for EPS as for EHPS. Technically, EHPS is less costly than EPS. However, we believe that EHPS is likely to be used, if at all, on the largest trucks and utility vehicles. As such, it would probably need to be heavier-duty than typical EPS systems and the agencies consider the net effect to place EHPS on par with EPS in terms of costs. The agencies consider EPS/EHPS technology to be on the flat portion of the learning curve and have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. The resultant costs are shown in Table 3-43.

Table 3-43 Costs of Electrical/Electro-hydraulic Power Steering (2010$)

Cost type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$87	$86	$84	$82	$80	$79	$77	$76	$74
IC	$22	$22	$18	$18	$18	$18	$18	$18	$18
TC	$109	$108	$101	$100	$98	$96	$95	$93	$92

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.3.2 Improved Accessories

The accessories on an engine, including the alternator, coolant and oil pumps are traditionally mechanically-driven. A reduction in CO_2 emissions and fuel consumption can be realized by driving them electrically, and only when needed ("on-demand").

Electric water pumps and electric fans can provide better control of engine cooling. For example, coolant flow from an electric water pump can be reduced and the radiator fan can be shut off during engine warm-up or cold ambient temperature conditions which will reduce warm-up time, reduce warm-up fuel enrichment, and reduce parasitic losses.

Indirect benefit may be obtained by reducing the flow from the water pump electrically during the engine warm-up period, allowing the engine to heat more rapidly and thereby reducing the fuel enrichment needed during cold starting of the engine. Further benefit may be obtained when electrification is combined with an improved, higher efficiency engine alternator. Intelligent cooling can more easily be applied to vehicles that do not typically carry heavy payloads, so larger vehicles with towing capacity present a challenge, as these vehicles have high cooling fan loads. Both agencies also included a higher efficiency alternator in this category to improve the cooling system.

The agencies considered whether to include electric oil pump technology for the rulemaking. Because it is necessary to operate the oil pump any time the engine is running, electric oil pump technology has insignificant effect on efficiency. Therefore, the agencies decided to not include electric oil pump technology for this final rule, consistent with the proposal.

In MYs 2012-2016 final rule, the agencies used the effectiveness value in the range of 1 to 2 percent based on technologies discussed above. NHTSA did not apply this technology to large pickup truck due to the utility requirement concern for this vehicle class.

For this final rule, consistent with the proposal, the agencies considered two levels of improved accessories. For level one of this technology (IACC1) NHTSA now incorporates a high efficiency alternator (70 percent efficiency). The second level of improved accessories (IACC2) adds the higher efficiency alternator and incorporates a mild regenerative alternator strategy, as well as intelligent cooling. NHTSA and EPA jointly reviewed the estimates of 1 to 2 percent effectiveness estimates used in the 2012-2016 final rule and TAR for level IACC1. More precisely, the agencies used effectiveness value in 1.2 to 1.8 percent range varying based on different vehicle subclasses. The incremental effectiveness for this technology in relative to EPS in the CAFE model is 0.91 to 1.61 percent. The combined effectiveness for IACC1 and IACC2 ranges from 3.1 to 3.9 percent and NHTSA applied incremental effectiveness of IACC2 in relative to IACC1 ranging from 1.74 to 2.55 percent.

In the 2012-2016 rule, the agencies estimated the DMC of IACC1 at $71 (2007$). Converting to 2010$, this DMC becomes $75 for this analysis, applicable in the 2015MY, and consistent with the heavy-duty GHG rule. The agencies consider IACC1 technology to be on the flat portion of the learning curve and have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter.

Cost is higher for IACC2 due to the inclusion of a higher efficiency alternator and a mild level of regeneration. The agencies estimate the DMC of the higher efficiency alternator and the regeneration strategy at $45 (2010$) incremental to IACC1, applicable in the 2015MY. Including the costs for IACC1 results in a DMC for IACC2 of $120 (2010$) relative to the baseline case and applicable in the 2015MY. The agencies consider the IACC2 technology to be on the flat portion of the learning curve. The agencies have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. The resultant costs are shown in Table 3-44.

Table 3-44 Costs for Improved Accessory Technology – Levels 1 & 2 (2010$)

Cost type	IACC Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	IACC1	$71	$70	$68	$67	$65	$64	$63	$62	$60
DMC	IACC2	$114	$112	$110	$107	$105	$103	$101	$99	$97
IC	IACC1	$18	$18	$14	$14	$14	$14	$14	$14	$14
IC	IACC2	$29	$29	$23	$23	$23	$23	$23	$23	$23
TC	IACC1	$89	$88	$82	$81	$80	$78	$77	$76	$75
TC	IACC2	$143	$141	$133	$131	$128	$126	$124	$122	$120

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost
Note that both levels of IACC technology are incremental to the baseline case.

3.4.3.3 Air Conditioner Systems

We have a detailed description of the A/C program in Chapter 5 of this joint TSD. The reader is directed to that chapter to learn the specifics of the program, the credits involved, and details behind the costs we have estimated. Table 3-45 is a copy of Table 5-18 showing the total costs for A/C controls used in this final rule.

Table 3-45 Total Costs for A/C Control Used in This Final rule (2010$)

Car/ Truck	Cost type	Rule	2017	2018	2019	2020	2021	2022	2023	2024	2025
Car	TC	Reference	$76	$75	$70	$69	$68	$67	$66	$65	$64
	TC	Control	$25	$40	$57	$65	$79	$77	$72	$71	$69
	TC	Both	$101	$115	$127	$134	$147	$144	$138	$135	$133
Truck	TC	Reference	$58	$57	$54	$53	$52	$51	$50	$49	$49
	TC	Control	$2	$46	$73	$82	$95	$93	$88	$86	$84
	TC	Both	$60	$103	$127	$134	$147	$144	$138	$135	$133
Fleet	TC	Both	$86	$111	$127	$134	$147	$144	$138	$135	$133

TC=Total cost

3.4.3.4 Stop-start (12V Micro Hybrid)

The stop-start technology we consider for this final rule, consistent with the proposal—also known as idle-stop or 12-volt micro-hybrid—is the most basic hybrid system that facilitates idle-stop capability. When vehicle comes to a stop, the system will automatically shut down the internal combustion engine and restarts the engine when vehicle starts to move again. This is especially beneficial to reduce emission and fuel consumption when vehicle spends significant amount of time stopping in inner city driving or a traffic jam. Along with other enablers, this system typically replaces the standard 12-volt starter with an improved unit capable of higher power and increased cycle life. These systems typically incorporate an improved battery to prevent voltage-droop on restart. Different from MY 2012-2016 rule, this technology is applied to all vehicle classes, including large pickup truck.

In MYs 2012-2016 final rule, even though EPA did not use 12 volt stop-start technology, NHTSA and EPA jointly reviewed the assumption. The effectiveness NHTSA used in the CAFE model for MYs 2012-2016 final rule ranged from 2 to 4 percent, depending on whether the vehicle is equipped with a 4-, 6- or 8-cylinder engine, with the 4-cylinder engine having the lowest range and the 8-cylinder having the highest. In this FRM analysis, consistent with the proposal, when combining IACC1, IACC2 and 12V stop-start system, the estimated effectiveness based on 2010 Ricardo study ranges from 4.8 percent to 5.9 percent. The agencies applied this effectiveness in the FRM analysis, consistent with the proposal. For CAFE modeling, the incremental effectiveness for 12V stop-start relative to IACC2 is 1.68 to 2.2 percent. Importantly, the effectiveness values presented here represent two-cycle effectiveness. Because stop-start technology provides considerable off-cycle benefits, both agencies apply a credit value to the technology. Off-cycle credits are discussed in Chapter 5 of this Joint TSD.

In the 2012-2016 rule, the agencies estimated the DMC at $282 (2007$) to $350 (2007$) for small cars through large trucks, respectively. Converting to 2010$, these DMCs become $295 (2010$) through $367 (2010$) for this analysis which are considered applicable in the 2015MY. The agencies consider 12V stop-start technology to be on the steep portion of the learning curve in the 2012-2016 timeframe and flat thereafter and have applied a medium complexity ICM of 1.39 through 2018 then 1.29 thereafter. The resultant costs are shown in Table 3-46.

Table 3-46 EPA and NHTSA Costs for 12V Micro Hybrid or 12V Stop-Start (2010$)

Cost type	Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	$287	$278	$270	$261	$254	$246	$239	$232	$225
DMC	Standard car	$287	$278	$270	$261	$254	$246	$239	$232	$225
DMC	Large car	$325	$315	$306	$296	$288	$279	$271	$262	$255
DMC	Small MPV	$325	$315	$306	$296	$288	$279	$271	$262	$255
DMC	Large MPV	$325	$315	$306	$296	$288	$279	$271	$262	$255
DMC	Truck	$356	$346	$335	$325	$315	$306	$297	$288	$279
IC	Small car	$114	$114	$85	$85	$84	$84	$84	$84	$83
IC	Standard car	$114	$114	$85	$85	$84	$84	$84	$84	$83
IC	Large car	$129	$129	$96	$96	$96	$95	$95	$95	$94
IC	Small MPV	$129	$129	$96	$96	$96	$95	$95	$95	$94
IC	Large MPV	$129	$129	$96	$96	$96	$95	$95	$95	$94
IC	Truck	$142	$141	$105	$105	$105	$105	$104	$104	$104
TC	Small car	$401	$392	$354	$346	$338	$330	$322	$315	$308
TC	Standard car	$401	$392	$354	$346	$338	$330	$322	$315	$308
TC	Large car	$454	$444	$402	$392	$383	$374	$366	$357	$349
TC	Small MPV	$454	$444	$402	$392	$383	$374	$366	$357	$349
TC	Large MPV	$454	$444	$402	$392	$383	$374	$366	$357	$349
TC	Truck	$498	$487	$441	$430	$420	$410	$401	$392	$383

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.3.5 Mild Hybrid

Mild hybrid systems, also called Higher Voltage Stop-Start and Belt Mounted Integrated Starter Generator (BISG) systems are similar to a micro-hybrid system, offering idle-stop functionality, except that they utilize larger electric machine and a higher capacity battery, typically 42 volts or above, thus enabling a limited level of regenerative braking unavailable for a MHEV. The larger electric machine and battery also enables a limited degree of power assist, which MHEV cannot provide. However, because of the limited torque capacity of the belt-driven design, these systems have a smaller electric machine, and thus less capability than crank-integrated or stronger hybrid systems. These systems replace the conventional alternator with a belt-driven starter/alternator and may add high voltage electrical accessories (which may include electric power steering and an auxiliary automatic transmission pump). The limited electrical requirements of these systems allow the use of lead-acid batteries or supercapacitors for energy storage, or the use of a small lithium-ion battery pack, as is modeled in this analysis. While the mild hybrid system was not applied in the NPRM analysis because the agencies did not have solid information regarding its likely architecture, effectiveness or cost, the agencies are including the technology in the final rule because we now have good information about it. Further, the agencies are making available credits for mild hybrid pickup trucks in an effort to encourage such technologies. Lastly, the simulation modeling and cost estimation results show that the mild hybrid system could be a cost effective technology.

For the BISG technology the agencies sized the system using a 15 kW starter/generator and 0.25 kWh Li-ion battery pack, which is similar to General Motors' eAssist BISG, which is available in MY 2012 Buick LaCrosse, Buick Regal, and Chevrolet Malibu vehicles. The agencies made this size system available to all vehicle subclasses, believing that manufacturers might use a similar strategy to control component complexity across the subclasses. As mentioned above, estimates were developed by ANL using Autonomie full vehicle simulation software. The absolute effectiveness for the CAFE analysis ranged from 8.5 to 11.6 percent depending on vehicle subclass. The effectiveness values include technologies that would be expected to incorporated with BISG which are stop/start (MHEV) and improved accessories (IACC1 and IACC2), however the effectiveness values do not include electric power steering (EPS).

The costs for the mild hybrid technology are all new for this final rule and were developed in a manner consistent with costs generated for strong hybrids. These costs are presented in sections 3.4.3.7 through 3.4.3.10 of this Joint TSD. The same cost and effectiveness results were applied by both NHTSA and EPA.

3.4.3.5.1 Integrated Motor Assist (IMA)/Crank Integrated Starter Generator (CISG)

IMA is a system developed and marketed by Honda[58] and is similar to CISG. They both utilize a thin axial electric motor bolted to the engine's crankshaft and connected to the transmission through a torque converter or clutch. The axial motor is motor/generator that typically operates above 100 volts (but lower than the stronger hybrid systems discussed below, which typically operate at around 300 volts) and can provide sufficient torque for launch as well as generate sufficient current to provide significant levels of brake energy recovery. The motor/generator also acts as the starter for the engine and can replace a typical accessory-driven alternator. Current IMA/CISG systems typically do not launch the vehicle on electric power alone, although some commercially available systems can cruise on electric power and dual-clutch IMA and CISG could be applied to all classes of vehicles. This technology is not used as an enabling technology in this FRM analysis, consistent with the proposal, by either EPA or NHTSA due to our expectation that manufacturers will be moving to more cost effective technologies.

EPA relied on a combination of certification data (comparing vehicles available with and without a hybrid system and backing out other components where appropriate) and manufacturer-supplied information to determine that the effectiveness of these systems in terms of CO_2 reduction is 30 percent for small cars, 25 percent for large cars, and 20 percent for minivans and small trucks similar to the range estimated by NHTSA for the respective vehicle classes. The effectiveness for small cars assumes engine downsizing to maintain approximately equivalent performance. The large car, minivan, and small truck effectiveness values assume less engine downsizing in order to improve vehicle performance and/or maintain towing and hauling performance.

In the 2012-2016 final rule, the agencies estimated the DMC at $1,973, $2,497, $2,508, $2,366 and $3,063 (all values in 2007$) for a small car, large car, minivan, small truck and large truck, respectively. For this final rule, the DMCs are $2,070, $2,620, $2,631 and $3,214 (all values in 2010$) for small car/standard car, large car, small MPV and large MPV/truck. All of these DMCs are considered applicable in the 2015MY. The agencies consider the IMA technology to be on the steep portion of the learning curve and have applied a high1 complexity ICM of 1.56 through 2018 then 1.35 thereafter. The resultant costs are as shown in Table 3-47. As noted earlier, the IMA technology is not included as an enabling technology in this analysis, although it is included as a baseline technology because it exists in the baseline fleet. The agencies moved away from this technology and applied P2 hybrids instead because P2 is more cost effective than IMA.

Table 3-47 Costs for IMA Hybrids (2010$)

Cost type	Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car/Standard car	$2,008	$1,947	$1,889	$1,832	$1,777	$1,724	$1,672	$1,622	$1,573
DMC	Large car	$2,541	$2,465	$2,391	$2,319	$2,250	$2,182	$2,117	$2,053	$1,992
DMC	Small MPV	$2,552	$2,475	$2,401	$2,329	$2,259	$2,191	$2,126	$2,062	$2,000
DMC	Large MPV/Truck	$3,118	$3,024	$2,933	$2,845	$2,760	$2,677	$2,597	$2,519	$2,443
IC	Small car/Standard car	$1,162	$1,159	$709	$707	$706	$704	$702	$701	$699
IC	Large car	$1,471	$1,467	$898	$895	$893	$891	$889	$887	$885
IC	Small MPV	$1,478	$1,473	$901	$899	$897	$895	$893	$891	$889
IC	Large MPV/Truck	$1,805	$1,799	$1,101	$1,098	$1,096	$1,093	$1,090	$1,088	$1,086
TC	Small car/Standard car	$3,170	$3,106	$2,598	$2,540	$2,483	$2,428	$2,375	$2,323	$2,273
TC	Large car	$4,013	$3,932	$3,289	$3,215	$3,143	$3,073	$3,006	$2,940	$2,877
TC	Small MPV	$4,029	$3,948	$3,302	$3,228	$3,156	$3,086	$3,018	$2,952	$2,889
TC	Large MPV/Truck	$4,923	$4,823	$4,034	$3,944	$3,856	$3,770	$3,687	$3,607	$3,529

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.3.6 HEV, PHEV, EV and Fuel Cell Vehicle Technologies

A hybrid vehicle is a vehicle that combines two or more sources of propulsion energy, where one uses a consumable fuel (like gasoline), and one is rechargeable (during operation, or by another energy source). Hybrid technology is well established in the U.S. market and more manufacturers are adding hybrid models to their lineups. Hybrids reduce fuel consumption through three major mechanisms:

- The internal combustion engine can be optimized (through downsizing, modifying the operating cycle, or other control techniques) to operate at or near its most efficient point more of the time. Power loss from engine downsizing can be mitigated by employing power assist from the secondary power source.
- Some of the energy normally lost as heat while braking can be captured and stored in the energy storage system for later use.
- The engine is turned off when it is not needed, such as when the vehicle is coasting or when stopped.

Hybrid vehicles utilize some combination of the three above mechanisms to reduce fuel consumption and CO_2 emissions. A fourth mechanism to reduce petroleum fuel consumption, available only to plug-in hybrids, is by substituting the petroleum fuel energy with energy from another source, such as the electric grid. The effectiveness of fuel consumption and CO_2 reduction depends on the utilization of the above mechanisms and how aggressively they are pursued. One area where this variation is particularly prevalent is in the choice of engine size and its effect on balancing fuel economy and performance. Some manufacturers choose not to downsize the engine when applying hybrid technologies. In these cases, performance is vastly improved, while fuel efficiency improves significantly less than if the engine was downsized to maintain the same performance as the conventional version. While this approach has been used in cars such as the Lexus 600h luxury vehicle, it is more likely to be used in the future for vehicles like trucks where towing and/or hauling are an integral part of their performance requirements. In these cases, if the engine is downsized, the battery can be quickly drained during a long hill climb with a heavy load, leaving only a downsized engine to carry the entire load. Because towing capability is currently a heavily-marketed truck attribute, manufacturers are hesitant to offer a truck with downsized engine which can lead to a significantly diminished towing performance when the battery state of charge level is low, and therefore engines are traditionally not downsized for these vehicles.

Although hybrid vehicles using other energy storage concepts (flywheel, hydraulic) have been developed, the automotive systems in production for passenger cars and light trucks are all hybrid electric vehicles (HEV) that use battery storage and electric drive systems. This appears likely to be the case for the foreseeable future. HEVs are part of a continuum of vehicles using systems with differing levels of electric drive and electric energy storage. This range of vehicles includes relatively basic system without electric energy storage such as engine start/stop systems; HEV systems with varying degrees of electric storage and electric drive system capability including mild-hybrid electric vehicles (MHEV) with limited capability but lower cost; strong hybrid electric vehicles (SHEV) with full hybridization capability such as the P2 hybrid technology which the agencies evaluate as a compliance option in this FRM; plug-in hybrid electric vehicles (PHEV) with differing degrees of all electric range and battery electric vehicles (EV) that rely entirely on electric drive and battery electric energy storage.

Different HEV, PHEV and EV concepts utilize these mechanisms differently, so they are treated separately for the purposes of this analysis. In many applications, particularly with PHEV and EV, the battery represents the most costly and system-limiting sub-component of the hybrid system. Currently, there are many battery chemistries being developed and refined for hybrid applications that are expected to enhance the performance of future hybrid vehicles. Section 3.4.3.6.4 contains a discussion of battery energy storage and the major hybrid concepts that were determined to be available during the MY 2017-2015 timeframe.

Fuel cell vehicles are a separate category of electric vehicle that rely entirely on electric propulsion with electricity produced on-board the vehicle using a proton-exchange-membrane fuel cell (PEMFC) fueled with hydrogen. Fuel cell vehicles under development are typically configured as a hybrid with battery storage used to provide brake energy recovery and improved response to fast transients in vehicle energy demand.

3.4.3.6.1 Power-split hybrid

Power-split hybrid (PSHEV) – a hybrid electric drive system that replaces the traditional transmission with a single planetary gear set and two motor/generators. The smaller motor/generator uses the engine to either charge the battery or to supply additional power to the drive motor. The second, more powerful motor/generator is permanently connected to the vehicle's final drive and always turns with the wheels. The planetary gear splits engine power between the first motor/generator and the drive motor to either charge the battery or supply power to the wheels. Power-split hybrids are not used as an enabling technology in this final rule, consistent with the proposal.

In MYs 2012-2016 final rule, EPA and NHTSA used a combination of manufacturer-supplied information and a comparison of vehicles available with and without a hybrid system from EPA's fuel economy test data to determine that the effectiveness is 19 to 36 percent for the classes to which it is applied. The estimate would depend on whether engine downsizing is also assumed. In the CAFE incremental model, the range of effectiveness used was 23 to 33 percent as engine downsizing is not assumed (and accounted for elsewhere).

For this analysis, in order to estimate baseline costs, the agencies are using power-split HEV costs generated by FEV as part of a tear-down study. In that study, FEV found the DMC of the entire power-split system (battery-pack and non-battery components) to be \$2,853 (2007\$), \$3,175 (2007\$), \$3,435 (2007\$), \$4,168 (2007\$) for vehicle sized, for example, like a Ford Fiesta, Ford Focus, Ford Fusion and Ford Flex, respectively. For this analysis, these values become \$2,967, \$3,302, \$3,572 and \$4,335, respectively, all in 2010 dollars. In the 2012-2016 final rule, the agencies estimated the DMC of a large truck power-split system at \$5,137 (2007\$) which becomes \$5,391 for this analysis (2010\$) and we are using this value for the large MPV vehicle class. All of these DMCs are considered applicable in the 2015MY. The agencies consider the power-split technology to be on the flat portion of the learning curve and have applied a high1 complexity ICM of 1.56 through 2018 then 1.35 thereafter. The resultant costs are as shown in Table 3-48. As noted earlier, the Power-split technology is not included as an enabling technology in this analysis, although it is included as a baseline technology because it exists in the baseline fleet.

Table 3-48 Costs for Power-Split Hybrids (2010$)

Cost type	Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	$2,820	$2,764	$2,709	$2,655	$2,602	$2,549	$2,498	$2,449	$2,400
DMC	Standard car	$3,139	$3,076	$3,015	$2,954	$2,895	$2,837	$2,781	$2,725	$2,671
DMC	Large car	$3,396	$3,328	$3,261	$3,196	$3,132	$3,070	$3,008	$2,948	$2,889
DMC	Small MPV	$4,120	$4,038	$3,957	$3,878	$3,801	$3,725	$3,650	$3,577	$3,505
DMC	Large MP	$5,125	$5,023	$4,922	$4,824	$4,727	$4,633	$4,540	$4,449	$4,360
IC	Small car	$1,663	$1,659	$1,017	$1,015	$1,013	$1,012	$1,010	$1,008	$1,007
IC	Standard car	$1,851	$1,846	$1,131	$1,129	$1,128	$1,126	$1,124	$1,122	$1,120
IC	Large car	$2,002	$1,998	$1,224	$1,222	$1,220	$1,218	$1,216	$1,214	$1,212
IC	Small MPV	$2,429	$2,424	$1,485	$1,483	$1,480	$1,478	$1,475	$1,473	$1,471
IC	Large MP	$3,021	$3,015	$1,847	$1,844	$1,841	$1,838	$1,835	$1,832	$1,829
TC	Small car	$4,483	$4,423	$3,725	$3,669	$3,615	$3,561	$3,508	$3,457	$3,406
TC	Standard car	$4,990	$4,923	$4,146	$4,084	$4,023	$3,963	$3,905	$3,847	$3,791
TC	Large car	$5,398	$5,326	$4,485	$4,418	$4,352	$4,288	$4,224	$4,162	$4,101
TC	Small MPV	$6,549	$6,462	$5,442	$5,361	$5,281	$5,202	$5,125	$5,050	$4,976
TC	Large MP	$8,146	$8,037	$6,769	$6,668	$6,568	$6,471	$6,375	$6,281	$6,190

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.3.6.2 2-mode hybrid

2-mode hybrid (2MHEV) – is a hybrid electric drive system that uses an adaptation of a conventional stepped-ratio automatic transmission by replacing some of the transmission clutches with two electric motors that control the ratio of engine speed to vehicle speed, while clutches allow the motors to be bypassed. This improves both the transmission torque capacity for heavy-duty applications and reduces fuel consumption and CO2 emissions at highway speeds relative to other types of hybrid electric drive systems. 2-mode hybrids were not been considered in the proposal and the agencies sought comments on whether or not 2-mode hybrids should be considered for vehicles with towing requirements, such as pickup trucks. However, no comments were received on their applicability in the future and thus consistent with the proposal, 2-mode hybrids were not included in the final rule analysis.

For MYs 2012-2016 final rule, the CAFE model considered a range of 23 to 33 percent with a midpoint of 28 percent, assuming no engine downsizing to preserve the utility nature of medium and large trucks (*e.g.*, maintaining full towing capability even in situations with low battery charge) and EPA estimates CO_2 emissions reduction effectiveness to be 25 percent for large trucks (LDT3 and LDT4 categories) based on vehicle certification data. EPA estimates an effectiveness of 40 percent for smaller vehicles.

The agencies have estimated the costs for 2-mode hybrids using costs used in the 2010 TAR. For this analysis, the 2-mode battery pack DMC is estimated at $1,100 (2010$) and the

DMC of non-battery components is estimated at $2,997 (2010$). The battery pack DMC is considered to be applicable for the 2025MY while the non-battery pack DMC would be applicable for the 2012MY. The agencies consider the 2-mode battery packs to be on the steep portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a high1 complexity ICM of 1.56 through 2018 then 1.35 thereafter. For 2-mode non-battery components, the agencies consider them to be on the flat portion of the learning curve in the 2017-2025 timeframe and have applied a high1 complexity ICM of 1.56 through 2018 then 1.35 thereafter. The resultant 2-mode hybrid costs are presented in Table 3-49.

Table 3-49 Costs for 2-Mode Hybrids (2010$)

Cost type	Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery-pack										
DMC	Small MPV/Large MPV/Truck	$2,148	$1,718	$1,718	$1,374	$1,374	$1,374	$1,374	$1,374	$1,100
IC		$688	$660	$399	$389	$389	$389	$389	$389	$380
TC		$2,835	$2,378	$2,118	$1,763	$1,763	$1,763	$1,763	$1,763	$1,479
Non-battery pack components										
DMC	Small MPV/Large MPV/Truck	$2,600	$2,548	$2,497	$2,447	$2,398	$2,350	$2,303	$2,257	$2,212
IC		$1,664	$1,660	$1,019	$1,018	$1,016	$1,015	$1,013	$1,012	$1,010
TC		$4,264	$4,208	$3,517	$3,465	$3,415	$3,365	$3,317	$3,269	$3,222
Battery-pack and non-battery pack components										
TC	Small MPV/Large MPV/Truck	$7,099	$6,586	$5,634	$5,228	$5,178	$5,128	$5,080	$5,032	$4,702

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.3.6.3 P2 Hybrid

A P2 hybrid is hybrid technology that uses a transmission-integrated electric motor placed between the engine and a gearbox or CVT and coupled to the engine crankshaft via a clutch. The engine and the drive motor are mechanically independent of each other, allowing the engine or motor to power the vehicle separately or combined. Disengaging the engine clutch allows all-electric operation and more efficient brake-energy recovery. The P2 HEV system is similar to the Honda IMA HEV architecture with the exception of the added clutch, and larger batteries and motors. Examples of this include the Hyundai Sonata HEV and Infiniti M35h. The agencies believe that the P2 is an example of a "strong" hybrid technology that is typical of what will be prevalent in the timeframe of this rule. The agencies could have equally chosen the power-split architecture as the representative HEV architecture. These two HEV's have similar average effectiveness values (combined city and highway fuel economy), though the P2 systems may have lower cost due to having only a single, smaller motor/generator.

For purposes of this rulemaking analysis, the agencies are assuming that P2 hybrids will become the dominant technology in the MYs 2017-2025 timeframe, replacing costlier power-split or 2-mode architectures while providing substantially similar efficiency improvement. At the present time, P2 hybrids are relatively new to the market and the agencies have not attempted to quantify any measurable performance differential between these technologies. As mentioned, the 2011 Hyundai Sonata, 2011 Volkswagen Touareg

Hybrid, the 2011 Porsche S Hybrid, and the 2012 Infiniti M35 Hybrid are examples of P2 hybrids currently in production and available to consumers. The agencies are aware of some articles in trade journals, newspapers and other reviews that some first generation P2 hybrid vehicles with automatic transmissions have trade-offs in NVH and drivability – though these reviews do not cover all of the P2 systems available today, and a number of reviews are very positive with respect to NVH and drivability. The agencies recognize that manufacturers will have several years to test, develop and improve P2 technology in the years before 2017. We expect that manufacturers will address any perceived integration issues in early production models. However, we believe it is important to continue to monitor development of P2 hybrids and market acceptance of this technology. We will continue to gather information on these issues and consider them as part of the mid-term evaluation.

The agencies requested comment regarding the potential of P2 hybrids to overcome these issues or others and we specifically sought comment from automakers developing and considering P2 technology on whether they believe these to be significant impediments to deployment and how they may be addressed. There were no comments submitted.

The effectiveness used for vehicle packages with the P2-hybrid configuration within this analysis reflects a conservative estimate of system performance. Vehicle simulation modeling of technology packages using the P-2 hybrid has recently been completed under a contract with Ricardo Engineering. The agencies have updated the effectiveness of hybrid electric vehicle packages using the new Ricardo vehicle simulation modeling runs for this analysis.

Due to the lower cost and comparative effectiveness of P2 hybrid in relative to other strong hybrid technologies, such as power-split hybrid and 2-mode hybrid, the agencies assume P2 hybrid application for all vehicle sub-classes in this FRM analysis, consistent with the proposal, and increased HEV effectiveness by approximately 2% comparing to 2012-2016 light duty GHG/CAFE final rule based on published data for new HEVs that have entered into production, such as 2011 Hyundai Sonata hybrid, 2010 Hyundai Elantra LPI HEV (Korean market only), 2011 Infiniti G35 Hybrid and 2011 Volkswagen Touareg Hybrid). In addition, for the Large Car, Minivan and Small Truck subclasses, the agencies further increased HEV effectiveness by assuming that towing capacity could be reduced from their current rating[rr] to approximately 1,500 pounds for some vehicles in these subclasses without significantly impacting consumers' need for utility in these vehicles.[ss] The agencies believe that consumers for these vehicles who require higher towing capacity could acquire it by purchasing a vehicle with a more capable non-hybrid powertrain (as they do today).[tt]

[rr] Current small SUVs and Minivans have an approximate average towing capacity of 2000 pounds (without a towing package), but range from no towing capacity to 3500 pounds.

[ss] We note that there are some gasoline vehicles in the large car/minivan/small truck segments sold today which do not have any towing rating.

[tt] The agencies recognize that assuming that certain consumers will choose to purchase non-hybrid vehicles in order to obtain their desired towing capacity could lead to some increase in fuel consumption and CO_2 emissions as compared to assuming that towing capacity is maintained for hybrid vehicles across the board. However, the

Moreover, it is likely that some fraction of consumers who purchase the larger engine option do so for purposes of hauling and acceleration performance, not just maximum towing.

A reduction in towing capacity allows greater engine downsizing, which increases estimated overall HEV system incremental effectiveness by 5 to 10 percent for Large Cars, Minivans, and Small Trucks, similar to the HEV effectiveness value assumed for Small Cars and Compact Cars.[uu]

Based on the recent Ricardo study, the effectiveness for P2 hybrid used in this FRM, consistent with the proposal, is 46.2 percent for subcompact and compact passenger cars, 48.6 percent for midsize passenger car, 49.4 percent for large passenger car, 46.1 percent for small light truck, 45.7 percent for midsize SUV, truck and minivan and 45.1 percent for large pickup truck.

The process for battery sizing for the P2 hybrids is explained in Section 3.4.3.8. The battery sizing is different for the 2008 and 2010 baseline vehicle fleets, because vehicle mass for each subclass is slightly different between the two baseline fleets, thus requiring a slightly different battery size to maintain equivalent performance. The battery sizes with no applied mass reduction are listed in Table 3-50.

Table 3-50 NHTSA Battery Sizes for P2 Hybrid Applied in Volpe Model without Mass Reduction (kWh)

Baseline Fleet	Subcompact PC/ Perf PC Compact PC/ Perf PC	Midsize PC/Perf PC	Large PC/Perf PC	Midsize LT Minivan	Small LT	Large LT
2008	0.81	1.00	1.16	1.28	1.04	1.49
2010	0.84	1.02	1.20	1.27	1.06	1.56

The agencies have applied a high complexity ICM to both the battery and non-battery component costs for P2 hybrid. But for battery for P2 hybrid, the ICM switches from short term value of 1.56 to long term value of 1.35 at 2024 while for the non-battery component the switch happens at 2018.

The costs for P2 hybrids without mass reduction as used in the Volpe model are listed in Table 3-51. The battery costs are calculated using the battery sizes for both the 2008 and 2010 baseline fleets. NHTSA accounts the cost impact from the interaction between mass reduction and sizing of the electrification system (battery and non-battery system) as a cost

agencies think it likely that the net improvement in fuel consumption and CO_2 emissions due to the increased numbers of hybrids available for consumers to choose will offset any potential increase in fuel consumption and CO_2 emissions resulting from consumers selecting the higher-performance non-hybrid powertrain vehicles.

[uu] The effectiveness of HEVs for heavier vehicles which require conventional towing capabilities is markedly less because the rated power of the IC engine must be similar to its non-hybrid brethren. As such, there is less opportunity for downsizing with these vehicles.

synergy as described in section 3.4.3.9. Estimated costs for P2 HEVs with mass reduction as used in the OMEGA model are presented in Sections 3.4.3.9 and 3.4.3.10 below.

Table 3-51 NHTSA Costs for P2 Hybrid Applied in Volpe Model without Mass Reduction (2010$)

Tech.	Cost Type	NHTSA Vehicle Class	Baseline Fleet	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$733	$711	$689	$669	$648	$629	$610	$592	$574
			2008	$726	$704	$683	$662	$642	$623	$604	$586	$569
Battery	DMC	Midsize PC/Perf PC	2010	$818	$793	$769	$746	$724	$702	$681	$661	$641
			2008	$809	$784	$761	$738	$716	$694	$674	$653	$634
Battery	DMC	Large PC/Perf PC	2010	$959	$931	$903	$876	$849	$824	$799	$775	$752
			2008	$946	$918	$890	$864	$838	$813	$788	$765	$742
Battery	DMC	Midsize LT Minivan	2010	$887	$860	$834	$809	$785	$761	$739	$716	$695
			2008	$885	$858	$832	$807	$783	$760	$737	$715	$693
Battery	DMC	Small LT	2010	$796	$773	$749	$727	$705	$684	$663	$643	$624
			2008	$787	$763	$740	$718	$697	$676	$655	$636	$617
Battery	DMC	Large LT	2010	$1,029	$998	$968	$939	$911	$884	$857	$831	$807
			2008	$1,020	$989	$960	$931	$903	$876	$850	$824	$799
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$1,474	$1,445	$1,416	$1,388	$1,360	$1,333	$1,306	$1,280	$1,254
			2008	$1,468	$1,438	$1,410	$1,381	$1,354	$1,327	$1,300	$1,274	$1,249
Non-battery	DMC	Midsize PC/Perf PC	2010	$1,645	$1,612	$1,580	$1,549	$1,518	$1,487	$1,457	$1,428	$1,400
			2008	$1,627	$1,595	$1,563	$1,531	$1,501	$1,471	$1,441	$1,413	$1,384
Non-battery	DMC	Large PC/Perf PC	2010	$1,949	$1,910	$1,872	$1,834	$1,798	$1,762	$1,727	$1,692	$1,658
			2008	$1,906	$1,868	$1,830	$1,794	$1,758	$1,723	$1,688	$1,655	$1,621
Non-battery	DMC	Midsize LT Minivan	2010	$1,817	$1,780	$1,745	$1,710	$1,676	$1,642	$1,609	$1,577	$1,546
			2008	$1,798	$1,762	$1,727	$1,693	$1,659	$1,626	$1,593	$1,561	$1,530
Non-battery	DMC	Small LT	2010	$1,587	$1,555	$1,524	$1,493	$1,464	$1,434	$1,406	$1,378	$1,350
			2008	$1,557	$1,526	$1,496	$1,466	$1,436	$1,408	$1,380	$1,352	$1,325
Non-battery	DMC	Large LT	2010	$1,918	$1,879	$1,842	$1,805	$1,769	$1,733	$1,699	$1,665	$1,631
			2008	$1,901	$1,863	$1,825	$1,789	$1,753	$1,718	$1,684	$1,650	$1,617
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$413	$411	$410	$409	$407	$406	$405	$404	$248
			2008	$409	$408	$406	$405	$404	$402	$401	$400	$246
Battery	IC	Midsize	2010	$461	$459	$458	$456	$455	$453	$452	$451	$277

		PC/Perf PC	2008	$456	$454	$453	$451	$450	$448	$447	$446	$274
Battery	IC	Large PC/Perf PC	2010	$541	$539	$537	$535	$534	$532	$530	$529	$325
			2008	$533	$532	$530	$528	$526	$525	$523	$522	$320
Battery	IC	Midsize LT Minivan	2010	$500	$498	$496	$495	$493	$492	$490	$489	$300
			2008	$499	$497	$495	$494	$492	$490	$489	$488	$299
Battery	IC	Small LT	2010	$449	$447	$446	$444	$443	$442	$440	$439	$270
			2008	$443	$442	$440	$439	$438	$436	$435	$434	$266
Battery	IC	Large LT	2010	$580	$578	$576	$574	$572	$571	$569	$567	$348
			2008	$575	$573	$571	$569	$567	$566	$564	$562	$345
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$943	$941	$578	$577	$576	$575	$574	$574	$573
			2008	$939	$937	$575	$574	$574	$573	$572	$571	$570
Non-battery	IC	Midsize PC/Perf PC	2010	$1,053	$1,050	$645	$644	$643	$642	$641	$640	$639
			2008	$1,041	$1,039	$638	$637	$636	$635	$634	$633	$632
Non-battery	IC	Large PC/Perf PC	2010	$1,247	$1,244	$764	$763	$762	$761	$759	$758	$757
			2008	$1,219	$1,217	$747	$746	$745	$744	$743	$741	$740
Non-battery	IC	Midsize LT Minivan	2010	$1,162	$1,160	$712	$711	$710	$709	$708	$707	$706
			2008	$1,150	$1,148	$705	$704	$703	$702	$701	$700	$699
Non-battery	IC	Small LT	2010	$1,015	$1,013	$622	$621	$620	$619	$618	$617	$616
			2008	$996	$994	$610	$610	$609	$608	$607	$606	$605
Non-battery	IC	Large LT	2010	$1,227	$1,224	$752	$751	$749	$748	$747	$746	$745
			2008	$1,216	$1,213	$745	$744	$743	$742	$741	$739	$738
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$1,145	$1,122	$1,099	$1,077	$1,056	$1,035	$1,015	$996	$822
			2008	$1,135	$1,111	$1,089	$1,067	$1,046	$1,025	$1,006	$986	$814
Battery	TC	Midsize PC/Perf PC	2010	$1,278	$1,252	$1,227	$1,202	$1,179	$1,155	$1,133	$1,111	$918
			2008	$1,264	$1,239	$1,213	$1,189	$1,166	$1,143	$1,121	$1,099	$907
Battery	TC	Large PC/Perf PC	2010	$1,500	$1,469	$1,440	$1,411	$1,383	$1,356	$1,330	$1,304	$1,077
			2008	$1,480	$1,449	$1,420	$1,392	$1,364	$1,337	$1,311	$1,286	$1,062
Battery	TC	Midsize LT Minivan	2010	$1,386	$1,358	$1,331	$1,304	$1,278	$1,253	$1,229	$1,205	$995
			2008	$1,383	$1,355	$1,327	$1,301	$1,275	$1,250	$1,226	$1,202	$993
Battery	TC	Small LT	2010	$1,245	$1,220	$1,195	$1,171	$1,148	$1,125	$1,104	$1,082	$894
			2008	$1,230	$1,205	$1,181	$1,157	$1,134	$1,112	$1,090	$1,069	$883
Battery	TC	Large LT	2010	$1,609	$1,576	$1,544	$1,513	$1,483	$1,454	$1,426	$1,399	$1,155
			2008	$1,595	$1,562	$1,531	$1,500	$1,470	$1,442	$1,414	$1,386	$1,145
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$2,418	$2,386	$1,994	$1,965	$1,936	$1,908	$1,881	$1,854	$1,827
			2008	$2,407	$2,375	$1,985	$1,956	$1,927	$1,899	$1,872	$1,845	$1,819

Non-battery	TC	Midsize PC/Perf PC	2010	$2,698	$2,663	$2,225	$2,192	$2,160	$2,129	$2,098	$2,068	$2,039
			2008	$2,668	$2,633	$2,201	$2,168	$2,137	$2,106	$2,075	$2,046	$2,016
Non-battery	TC	Large PC/Perf PC	2010	$3,196	$3,155	$2,636	$2,597	$2,559	$2,522	$2,486	$2,450	$2,415
			2008	$3,125	$3,085	$2,577	$2,540	$2,503	$2,466	$2,431	$2,396	$2,362
Non-battery	TC	Midsize LT Minivan	2010	$2,979	$2,940	$2,457	$2,421	$2,386	$2,351	$2,317	$2,284	$2,252
			2008	$2,949	$2,910	$2,432	$2,396	$2,361	$2,327	$2,294	$2,261	$2,229
Non-battery	TC	Small LT	2010	$2,602	$2,568	$2,146	$2,115	$2,084	$2,054	$2,024	$1,995	$1,966
			2008	$2,554	$2,520	$2,106	$2,075	$2,045	$2,015	$1,986	$1,958	$1,930
Non-battery	TC	Large LT	2010	$3,144	$3,103	$2,593	$2,555	$2,518	$2,482	$2,446	$2,411	$2,376
			2008	$3,116	$3,076	$2,570	$2,533	$2,496	$2,460	$2,424	$2,389	$2,355

3.4.3.6.4 Plug-In Hybrid

Plug-In Hybrid Electric Vehicles (PHEVs) are very similar to Hybrid Electric Vehicles, but with three significant functional differences. The first is the addition of a means to charge the battery pack from an outside source of electricity (*e.g.*, the electric grid). Second, a PHEV would have a larger battery pack with more energy storage, and a greater capability to be discharged. Finally, a PHEV would have a control system that allows the battery pack to be significantly depleted during normal operation.

Table 3-52 below, illustrates how PHEVs compare functionally to both hybrid electric vehicles (HEV) and electric vehicles (EV). These characteristics can change significantly within each vehicle class/subclass, so this is simply meant as an illustration of the general characteristics. In reality, the design options are so varied that all these vehicles exist on a continuum with HEVs on one end and EVs on the other.

Table 3-52 Conventional, HEVs, PHEVs, and EVs Compared

	Increasing Electrification			
Attribute	Conventional	HEV	PHEV	EV
Drive Power	Engine	Blended Engine/Electric	Blended Engine/Electric	Electric
Engine Size	Full Size	Full Size or Smaller	Smaller or Much Smaller	No Engine
Electric Range	None	None to Very Short	Short to Medium	Medium to Long
Battery Charging	None	On-Board	Grid/On-Board	Grid Only

Deriving some of their propulsion energy from the electric grid provides several advantages for PHEVs. PHEVs offer a significant opportunity to replace petroleum used for transportation energy with domestically-produced electricity. The reduction in petroleum usage does, of course, depend on the amount of electric drive the vehicle is capable of under its duty cycle. PHEVs also provide electric utilities the possibility to increase electric generation during "off-peak" periods overnight when there is excess generation capacity and electricity prices are lower. Utilities like to increase this "base load" because it increases overall system efficiency and lowers average costs. PHEVs can lower localized emissions of criteria pollutants and air toxics especially in urban areas by operating on electric power. The emissions from the power generation occur outside the urban area at the power generation plant which provides health benefits for residents of the more densely populated urban areas by moving emissions of ozone precursors out of the urban air shed. Unlike most other alternative fuel technologies, PHEVs can initially use an existing infrastructure for refueling (charging and liquid refueling) so investments in infrastructure may be reduced.

In analyzing the impacts of grid-connected vehicles like PHEVs and EVs, the emissions from the electrical generation can be accounted for if a full upstream and downstream analysis is desired. While this issue is being studied on an on-going basis, upstream CO_2 emissions are not unique to grid-connected technologies and so are not included in this analysis. The respective agencies' RIAs and NHTSA's EIS have more information on upstream emissions.

PHEVs will be considerably more costly than conventional vehicles and some other advanced technologies due to the fact that PHEVs require both conventional internal combustion engine and electrical driving system and the larger expensive battery pack. To take full advantage of their capability, consumers would have to be willing to charge the vehicles during electricity off-peak hours during the night, and would need access to electric power where they park their vehicles. For many urban dwellers who may park on the street, or in private or public lots or garages, charging may not be practical. Charging may be possible at an owner's place of work, but that would increase grid loading during peak hours which would eliminate some of the benefits to utilities of off-peak charging versus on-peak. Oil savings will still be the same in this case assuming the vehicle can be charged fully.

The effectiveness potential of PHEVs depends on many factors, the most important being the energy storage capacity designed into the battery pack. To estimate the fuel consumption and tailpipe CO_2 reduction potential of PHEVs, EPA has developed an in-house vehicle energy model (PEREGRIN) to estimate the fuel consumption/CO_2 emissions reductions of PHEVs. This model is based on the PERE (Physical Emission Rate Estimator) physics-based model used as a fuel consumption input for EPA's MOVES mobile source emissions model.

How EPA Estimates PHEV Effectiveness

The PHEV small car, large car, minivan and small trucks were modeled using parameters from a midsize car similar to today's hybrids and scaled to each vehicle's weight. The large truck PHEV was modeled separately assuming no engine downsizing. PHEVs can have a wide variation in the All Electric Range (AER) that they offer. Some PHEVs are of the "blended" type where the engine is on during most of the vehicle operation, but the proportion of electric energy that is used to propel the vehicle is significantly higher than that used in a PSHEV or 2MHEV. Each PHEV was modeled with enough battery capacity for a 20-mile-equivalent AER and a power requirement to provide similar performance to a hybrid vehicle. 20 miles was selected because it offers a good compromise for vehicle performance, weight, battery packaging and cost. Given expected near-term battery capability, a 20 mile range represents the likely capability that will be seen in PHEVs in the near-to-mid term.

To calculate the total energy use of a PHEV, the PHEV can be thought of as operating in two distinct modes, electric (EV) mode, and hybrid (HEV) mode. At the tailpipe, the CO_2 emissions during EV operation are zero. The EV mode fuel economy can then be combined with the HEV mode fuel economy using the Utility Factor calculation in SAE J1711 to determine a total MPG value for the vehicle. (See Table 3-53)

Table 3-53 Sample Calculation of PHEV Gasoline-Equivalent CO_2 Reduction

	Midsize Car	Large Truck
EV energy comb (0.55 city / 0.45 hwy)	0.252 kwh/mi	0.429 kwh/mi
EV range (from PEREGRIN)	20 miles	20 miles
SAE J1711 utility factor	0.30	0.30
HEV mode comb FE (0.55 city / 0.45 hwy)	49.1 mpg	25.6 mpg
Total UF-adjusted FE (UF*FCEV + (1-UF)*FCHEV)	70.1 mpg	36.6 mpg
Baseline FE	29.3 mpg	19.2 mpg
Percent FE gain	139%	90%
Percent CO_2 reduction	-58%	-47%

Calculating a total fuel consumption and tailpipe CO_2 reduction based on model outputs and the Utility Factor calculations results in a 58 percent reduction for small cars, large cars, minivans, and small trucks. For large trucks, the result is a 47 percent reduction. The lower improvement is due to less engine downsizing in the large truck class.

How NHTSA Estimates PHEV Effectiveness

For purposes of CAFE analysis, we assume that all future PHEVs during the rulemaking timeframe will meet the range requirements to qualify as a dual fuel vehicle. When calculating the fuel economy of a dual-fuel PHEV, NHTSA uses a petroleum equivalency factor for electricity consumption as stated in 49 U.S.C. 32904 and 32905.

When deciding PHEV and EV effectiveness, NHTSA referenced the fuel economy of 3 pairs of vehicles for which NHTSA has fuel economy data in the CAFE database. These three vehicles pairs are MiniE electric vehicle versus gasoline powered Mini with automatic transmission, Tesla Roadster electric vehicle versus gasoline powered rear-wheel-drive Lotus Elise Sedan with a 6-speed manual transmission, and Nissan Leaf electric vehicle versus gasoline powered Nissan Sentra with automatic transmission. The fuel economy and fuel consumption for the first two pairs are shown in Table 3-54. Nissan Leaf information is used but not shown in the table because it is confidential information. Because technologies are applied in the CAFE model in an incremental manner, the effectiveness for each technology is incremental to the previous technology. In the electrification decision tree of the CAFE model, the order of technology selection starts from gasoline only powertrain, then moves to strong hybrid, to plug-in hybrid electric vehicle, and finally to electric vehicle. So the incremental effectiveness for each step has to be defined.

Table 3-54 EV Fuel Economy and Fuel Consumption

104 mile range (Mini website)	Fuel economy (mpg)	Fuel consumption (gpm)
MiniE (mpg)	342.4	0.0029206
Mini Gas ATX (mpg)	38.6	0.0259067
227 mile range (EPA)		
Tesla Roadster	346.8	0.0028835
Lotus Elise sedan M6 RWD	30.6	0.0326797

In order to calculate the effectiveness of PHEV for purposes of a CAFE standard, fuel economy for strong hybrid electric vehicle (SHEV) is calculated first using the incremental effectiveness of strong hybrid from LPM model which is around 46 percent. For example, the derived fuel economy for SHEV based on Mini Gas ATX is 71.7 mpg. Then the fuel economy from gasoline source for PHEV is assumed to be the same as SHEV fuel economy, i.e. 71.7 mpg in the case of Mini E. The petroleum equivalent fuel economy from the electricity source is set to be the same as the EV fuel economy, e.g., 342.4 mpg in the case of Mini E. The combined fuel economy for PHEV is calculated using the 50-50 weighting factor as follows.

$$PHEV\ Combined\ Fuel\ Economy = \frac{1}{\frac{Gasoline\ FE\ Weighing\ Factor}{Gasoline\ Fuel\ Economy} + \frac{Electric\ FE\ Weighing\ Factor}{EV\ Fuel\ Economy}}$$

$$= \frac{1}{\frac{0.5}{71.7} + \frac{0.5}{342.4}} = 118.6\ mpg$$

Consistent with 49 U.S.C. 32904 and 32905, NHTSA is using a 50-50 weighting factor in the calculation above for CAFE model analysis of PHEV through 2019. After 2019, NHTSA will use the utility factor method defined by SAE standard J1711 for calculating CAFE fuel economy of PHEV. NHTSA expects that a PHEV with a 30 mile charge depleting range may reasonably represent the PHEVs that manufacturers may produce in MYs 2017 to 2025. According to SAE standard J2841, a vehicle with 30 mile charge depleting range has a 0.668 city specific utility factor and a 0.337 highway specific utility factor, which together give a 0.52 combined utility factor (55% city/45% highway split). Therefore NHTSA selected a PHEV with a 30 mile range for the CAFE model analysis, and the selection of a PHEV with a 30 mile range maintains continuity between pre-2020 and post-2020 PHEV fuel economy calculations. NHTSA assumes a 0.50 utility factor for MY2020 and beyond. In the FRM analysis, consistent with the proposal, EPA models a 20-mile range and a 40-mile range PHEV.

The incremental fuel consumption reduction for PHEV is then calculated in relative to strong HEV. Using the example of Mini E, the incremental fuel consumption reduction for PHEV relative to SHEV is 39.5 percent as shown below.

$$Incremental\ Fuel\ Consumption\ Reduction\ for\ PHEV = \frac{\left(\frac{1}{PHEV\ Fuel\ Economy} - \frac{1}{SHEV\ Fuel\ Economy}\right)}{\frac{1}{SHEV\ Fuel\ Economy}} x100\%$$

$$= \frac{\left(\frac{1}{118.6} - \frac{1}{71.7}\right)}{\frac{1}{71.7}} x100\% = -39.5\%$$

Table 3-55 lists the incremental effectiveness calculation for two pairs of vehicles, MiniE and Tesla Roaster. Incremental fuel consumption calculation for PHEV based on Nissan Leaf is not shown in Table 3-55 due to confidentiality of the fuel economy rating. The derived incremental effectiveness for Nissan Leaf is 40.6%. The average incremental effectiveness of these three pairs of vehicles is 40.65 percent which is used in CAFE modeling.

Table 3-55 Incremental Effectiveness Calculation for purposes of CAFE modeling

Mini E

	Gasoline	SHEV2	PHEV1	EV1
Combined Fuel Economy [mpg]	***38.6***	71.7	118.6	***342.4***
Gasoline Fuel Economy [mpg]		71.7	71.7	
Electric Petroleum Equivalent Fuel Economy [mpg]			342.4	
Combined Fuel Consumption[gpm]		0.0139414	0.0084310	0.0029206
Gasoline Fuel Consumption [gpm]		0.0139414	0.0139414	
Incremental Combined Fuel Consumption [%]			**39.5%**	**65.4%**
Gasoline Weighing Factor[%]			50%	0%
Electricity Weighing Factor [%]			50%	100%

Tesla

	Gasoline	SHEV2	PHEV1	EV1
Combined Fuel Economy [mpg]	***30.6***	56.7	97.4	***346.8***
Gasoline Fuel Economy [mpg]		56.7	56.7	
Electric Petroleum Equivalent Fuel Economy [mpg]			346.8	
Combined Fuel Consumption[gpm]		0.017647	0.0102653	0.0028835
Gasoline Fuel Consumption [gpm]		0.017647	0.0176471	
Incremental Combined Fuel Consumption [%]			**41.8%**	**71.9%**
Gasoline Weighing Factor[%]			50%	0%

Electricity Weighing Factor [%]			50%	100%

Once the fuel economy of the PHEV is calculated, the effectiveness of PHEV incremental to EV can be calculated similarly using the formula below.

$$Incremental\ Fuel\ Consumption\ Improvement\ for\ EV = \frac{(\frac{1}{EV\ Fuel\ Economy} - \frac{1}{PHEV\ Fuel\ Economy})}{\frac{1}{PHEV\ Fuel\ Economy}} x100\%$$

The average effectiveness for the three pairs of vehicles of 68.54% is used in CAFE modeling.

The cost of PHEV consists of three parts, the cost for battery, the cost for non-battery systems and the cost for charger and the labor to install it. The battery sizing is calculated as in Section 3.4.3.8 and listed in Table 3-56. Costs for PHEVs without mass reduction as used in the Volpe model are listed in Table 3-57 to Table 3-61. NHTSA accounts the cost impact from the interaction between mass reduction and sizing of the electrification system (battery and non-battery system) as a cost synergy as described in section 3.4.3.9. Sections 3.4.3.9 and 3.4.3.10 contain the cost for PHEVs with mass reduction as used in EPA's OMEGA model. PHEV20 and PHEV40 are sized by EPA with the methodologies discussed in section 3.4.3.8.

Table 3-56 NHTSA Battery Sizes for PHEV30 Hybrid Applied in Volpe Model without Mass Reduction (kWh)

Baseline Fleet	Subcompact PC/ Perf PC Compact PC/ Perf PC	Midsize PC/Perf PC	Large PC/Perf PC	Midsize LT Minivan	Small LT	Large LT
2008	10.42	12.82	15.21	17.09	13.48	19.73
2010	10.81	13.13	15.79	16.94	13.69	20.27

The battery pack DMCs for PHEV20 and PHEV40 are calculated using ANL's BatPaC model. NHTSA modeled a PHEV 30 for this final rule, for which NHTSA averaged the costs of PHEV20s and PHEV40s.

The agencies have applied a high complexity ICM to non-battery component cost for PHEV and PHEV charger, which switch from short term value of 1.56 to long term value of 1.35 at 2018. The agencies applied a higher ICM factor to the battery of PHEV due to the fact that it a more complex technology. The ICM for PHEV battery switches from short term value of 1.77 to long term value of 1.50 at 2024.

Table 3-57 NHTSA Costs Applied in Volpe Model for PHEV30 with No Mass Reduction (2010$)

Tech.	Cost Type	NHTSA Vehicle Class	Baseline Fleet	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$6,208	$8,259	$8,259	$6,607	$6,607	$6,607	$6,607	$6,607	$5,286
			2008	$6,095	$8,097	$8,097	$6,477	$6,477	$6,477	$6,477	$6,477	$5,182
Battery	DMC	Midsize PC/Perf PC	2010	$7,415	$5,932	$5,932	$4,746	$4,746	$4,746	$4,746	$4,746	$3,797
			2008	$7,251	$5,801	$5,801	$4,640	$4,640	$4,640	$4,640	$4,640	$3,712
Battery	DMC	Large PC/Perf PC	2010	$9,835	$7,868	$7,868	$6,294	$6,294	$6,294	$6,294	$6,294	$5,035
			2008	$9,610	$7,688	$7,688	$6,150	$6,150	$6,150	$6,150	$6,150	$4,920
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$2,586	$2,535	$2,484	$2,434	$2,386	$2,338	$2,291	$2,245	$2,200
			2008	$2,522	$2,472	$2,422	$2,374	$2,326	$2,280	$2,234	$2,190	$2,146
Non-battery	DMC	Midsize PC/Perf PC	2010	$3,252	$3,187	$3,124	$3,061	$3,000	$2,940	$2,881	$2,824	$2,767
			2008	$3,132	$3,070	$3,008	$2,948	$2,889	$2,831	$2,775	$2,719	$2,665
Non-battery	DMC	Large PC/Perf PC	2010	$4,685	$4,591	$4,499	$4,409	$4,321	$4,235	$4,150	$4,067	$3,986
			2008	$4,494	$4,405	$4,316	$4,230	$4,145	$4,063	$3,981	$3,902	$3,824
Charger	DMC	All	2008/2010	$210	$168	$168	$134	$134	$134	$134	$134	$108
Charger Labor	DMC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$2,671	$2,579	$2,579	$2,506	$2,506	$2,506	$2,506	$2,506	$1,578
			2008	$2,622	$2,532	$2,532	$2,460	$2,460	$2,460	$2,460	$2,460	$1,550
Battery	IC	Midsize PC/Perf PC	2010	$3,190	$3,081	$3,081	$2,993	$2,993	$2,993	$2,993	$2,993	$1,885
			2008	$3,119	$3,012	$3,012	$2,927	$2,927	$2,927	$2,927	$2,927	$1,844
Battery	IC	Large PC/Perf PC	2010	$4,231	$4,086	$4,086	$3,970	$3,970	$3,970	$3,970	$3,970	$2,501
			2008	$4,134	$3,993	$3,993	$3,879	$3,879	$3,879	$3,879	$3,879	$2,444
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$1,655	$1,651	$1,014	$1,012	$1,011	$1,009	$1,008	$1,006	$1,005
			2008	$1,614	$1,610	$989	$987	$986	$984	$983	$981	$980
Non-battery	DMC	Midsize PC/Perf PC	2010	$2,081	$2,077	$1,275	$1,273	$1,271	$1,269	$1,267	$1,265	$1,264
			2008	$2,004	$2,000	$1,228	$1,226	$1,224	$1,222	$1,220	$1,219	$1,217
Non-battery	DMC	Large PC/Perf PC	2010	$2,997	$2,991	$1,836	$1,834	$1,831	$1,828	$1,825	$1,823	$1,820
			2008	$2,875	$2,869	$1,762	$1,759	$1,756	$1,754	$1,751	$1,749	$1,746
Charger	IC	All	2008/2010	$67	$65	$65	$62	$62	$62	$62	$62	$37
Charger Labor	IC	All	2008/2010	$0	$0	$0	$0	$0	$0	$0	$0	$0

Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$8,878	$7,545	$7,545	$6,479	$6,479	$6,479	$6,479	$6,479	$4,757
			2008	$8,717	$7,408	$7,408	$6,361	$6,361	$6,361	$6,361	$6,361	$4,670
Battery	TC	Midsize PC/Perf PC	2010	$10,605	$9,013	$9,013	$7,739	$7,739	$7,739	$7,739	$7,739	$5,682
			2008	$10,370	$8,813	$8,813	$7,567	$7,567	$7,567	$7,567	$7,567	$5,556
Battery	TC	Large PC/Perf PC	2010	$14,066	$11,954	$11,954	$10,264	$10,264	$10,264	$10,264	$10,264	$7,536
			2008	$13,744	$11,681	$11,681	$10,030	$10,030	$10,030	$10,030	$10,030	$7,364
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$4,241	$4,186	$3,498	$3,446	$3,396	$3,347	$3,299	$3,251	$3,205
			2008	$4,136	$4,082	$3,411	$3,361	$3,312	$3,264	$3,217	$3,171	$3,126
Non-battery	TC	Midsize PC/Perf PC	2010	$5,333	$5,264	$4,399	$4,334	$4,271	$4,209	$4,148	$4,089	$4,031
			2008	$5,136	$5,069	$4,236	$4,174	$4,113	$4,054	$3,995	$3,938	$3,882
Non-battery	TC	Large PC/Perf PC	2010	$7,682	$7,582	$6,336	$6,243	$6,152	$6,063	$5,975	$5,890	$5,806
			2008	$277	$233	$233	$197	$197	$197	$197	$197	$145
Charger	TC	All	2008/2010	$277	$233	$233	$197	$197	$197	$197	$197	$145
Charger Labor	TC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010

3.4.3.6.5 Electric vehicles

Electric vehicles (EV) – are vehicles with all-electric drive and with vehicle systems powered by energy-optimized batteries charged primarily from grid electricity. While the 2016 FRM did not anticipate a significant penetration of EVs, in this analysis, EVs with several ranges have been included. The GHG effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule which is 100 percent GHG reduction. Per 49 U.S.C. 32904, NHTSA uses the Petroleum Equivalency Factor (PEF) in calculating the effectiveness for EVs as stated in the section above for PHEV. The PEF is determined by the U.S. Department of Energy as specified in 10 CFR Part 474. The PEF accounts for U.S. average fossil-fuel electricity generation and transmission efficiencies, petroleum refining and distribution efficiency, the energy content of gasoline, and includes a 0.15 divisor to incentivize the use of electricity in vehicles. The current PEF for electricity is 82.049 kWh per gallon of gasoline.

Once the fuel economy of the PHEV is calculated as shown in the previous section, the effectiveness of PHEV incremental to EV can be calculated similarly using the formula below.

$$\text{Incremental Fuel Consumption Improvement for EV} = \frac{\left(\frac{1}{\text{EV Fuel Economy}} - \frac{1}{\text{PHEV Fuel Economy}}\right)}{\frac{1}{\text{PHEV Fuel Economy}}} x100\%$$

The average effectiveness for the three pairs of vehicles of 68.54% is used in CAFE modeling.

Battery costs assume that battery packs for EV applications will be designed to last for the full useful life of the vehicle at a useable state of charge equivalent to 80% of the nominal battery pack capacity. NHTSA included two levels of EVs, a 75-mile range EV and a 150-mile range EV in this FRM analysis, consistent with the proposal. As this technology is entering the market, it is expected that the OEMs will try to keep the cost low at the beginning so that there will be more penetration. Due to the high cost of the battery packs at this early stage of EVs, OEM will try to limit the battery pack size to reduce cost. Also the early adopters for this technology are normally urban drivers and range anxiety is not believed to be a big concern to them. Therefore NHTSA applied a 75-mile range EV for early adoption of this technology in the market, up to 5% penetration. As the technology develops and as the market penetration increases beyond 5%, NHTSA expects that OEMs would provide longer driving range to help the consumers overcome range anxiety. NHTSA applied 150-mile EV for this broad market adoption of this technology.

The cost of an EV consists of three parts, cost of battery pack, cost of non-battery systems, and cost of charger and charger installation labor. An algorithm was used to select battery sizes. The algorithm is described in Section 3.4.3.8 and the battery sizes applied in the Volpe model for each type of EV and vehicle subclass are listed in Table 3-63.

Table 3-58 NHTSA Battery Sizes for EVs Applied in Volpe Model with No Mass Reduction (kWh)

	Baseline Fleet	Subcompact PC/ Perf PC Compact PC/ Perf PC	Midsize PC/Perf PC	Large PC/Perf PC	Midsize LT Minivan	Small LT	Large LT
EV75	2008	22.79	28.03	33.28	n/a	29.48	n/a
	2010	23.65	28.72	34.54	n/a	29.95	n/a
EV100	2008	30.39	37.38	44.37	n/a	39.30	n/a
	2010	31.54	38.30	46.05	n/a	39.94	n/a
EV150	2008	45.58	56.07	66.55	n/a	58.96	n/a
	2010	47.31	57.45	69.08	n/a	59.90	n/a

The agencies have applied a high complexity ICM to non-battery component cost for EVs and EV chargers, which switch from short term value of 1.56 to long term value of 1.35 at 2018. The agencies applied a higher ICM factor to the battery of EVs due to the fact that it a more complex technology. The ICM for EV battery switches from short term value of 1.77 to long term value of 1.50 at 2024. The agencies present costs of EVs in Sections 3.4.3.9 and 3.4.3.10. The costs of EVs without mass reduction as applied in Volpe model are listed in Table 3-58 to Table 3-60. NHTSA accounts the cost impact from the interaction between mass reduction and sizing of electrification system (battery and non-battery system) as cost synergy as described in section 3.4.3.9.

Table 3-59 NHTSA Costs for EV75 Applied in Volpe Model with No Mass Reduction (2010$)

Tech.	Cost Type	NHTSA Vehicle Class	Baseline Fleet	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$10,324	$8,259	$8,259	$6,607	$6,607	$6,607	$6,607	$6,607	$5,286
			2008	$10,121	$8,097	$8,097	$6,477	$6,477	$6,477	$6,477	$6,477	$5,182
Battery	DMC	Midsize PC/Perf PC	2010	$12,140	$9,712	$9,712	$7,769	$7,769	$7,769	$7,769	$7,769	$6,215
			2008	$11,881	$9,505	$9,505	$7,604	$7,604	$7,604	$7,604	$7,604	$6,083
Battery	DMC	Large PC/Perf PC	2010	$15,634	$12,507	$12,507	$10,006	$10,006	$10,006	$10,006	$10,006	$8,005
			2008	$15,238	$12,190	$12,190	$9,752	$9,752	$9,752	$9,752	$9,752	$7,802
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$410	$398	$386	$375	$363	$352	$345	$338	$332
			2008	$354	$343	$333	$323	$313	$304	$298	$292	$286
Non-battery	DMC	Midsize PC/Perf PC	2010	$1,267	$1,229	$1,193	$1,157	$1,122	$1,088	$1,067	$1,045	$1,024
			2008	$1,156	$1,122	$1,088	$1,055	$1,024	$993	$973	$954	$935
Non-battery	DMC	Large PC/Perf PC	2010	$2,236	$2,169	$2,104	$2,041	$1,980	$1,920	$1,882	$1,844	$1,808
			2008	$2,080	$2,018	$1,957	$1,899	$1,842	$1,786	$1,751	$1,716	$1,681
Charger	DMC	All	2008/2010	$395	$316	$316	$253	$253	$253	$253	$253	$202
Charger Labor	DMC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$4,441	$4,289	$4,289	$4,167	$4,167	$4,167	$4,167	$4,167	$2,625
			2008	$4,354	$4,205	$4,205	$4,086	$4,086	$4,086	$4,086	$4,086	$2,573
Battery	IC	Midsize PC/Perf PC	2010	$5,222	$5,044	$5,044	$4,901	$4,901	$4,901	$4,901	$4,901	$3,087
			2008	$5,111	$4,936	$4,936	$4,796	$4,796	$4,796	$4,796	$4,796	$3,021
Battery	IC	Large PC/Perf PC	2010	$6,725	$1,717	$1,712	$1,708	$1,703	$1,699	$1,696	$1,693	$1,090
			2008	$6,555	$6,331	$6,331	$6,151	$6,151	$6,151	$6,151	$6,151	$3,874

Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$316	$315	$314	$313	$313	$312	$311	$311	$200
			2008	$272	$272	$271	$270	$269	$269	$268	$268	$172
Non-battery	DMC	Midsize PC/Perf PC	2010	$976	$973	$970	$968	$965	$963	$961	$960	$618
			2008	$890	$888	$885	$883	$881	$878	$877	$876	$563
Non-battery	DMC	Large PC/Perf PC	2010	$1,722	$18	$18	$18	$18	$18	$18	$18	$10
			2008	$1,602	$1,597	$1,593	$1,588	$1,584	$1,580	$1,578	$1,575	$1,014
Charger	IC	All	2008/2010	$126	$121	$121	$117	$117	$117	$117	$117	$70
Charger Labor	IC	All	2008/2010	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$14,765	$12,548	$12,548	$10,775	$10,775	$10,775	$10,775	$10,775	$7,911
			2008	$14,475	$12,302	$12,302	$10,563	$10,563	$10,563	$10,563	$10,563	$7,755
Battery	TC	Midsize PC/Perf PC	2010	$17,362	$14,755	$14,755	$12,670	$12,670	$12,670	$12,670	$12,670	$9,302
			2008	$16,992	$14,441	$14,441	$12,400	$12,400	$12,400	$12,400	$12,400	$9,104
Battery	TC	Large PC/Perf PC	2010	$22,359	$19,002	$19,002	$16,317	$16,317	$16,317	$16,317	$16,317	$11,980
			2008	$21,793	$18,521	$18,521	$15,903	$15,903	$15,903	$15,903	$15,903	$11,676
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$726	$713	$700	$688	$676	$664	$657	$649	$532
			2008	$626	$615	$603	$593	$582	$572	$566	$559	$458
Non-battery	TC	Midsize PC/Perf PC	2010	$2,243	$2,203	$2,163	$2,125	$2,087	$2,051	$2,028	$2,005	$1,642
			2008	$2,047	$2,010	$1,973	$1,938	$1,904	$1,871	$1,850	$1,829	$1,498
Non-battery	TC	Large PC/Perf PC	2010	$3,959	$3,887	$3,817	$3,749	$3,683	$3,619	$3,578	$3,538	$2,897
			2008	$3,682	$3,615	$3,550	$3,487	$3,426	$3,367	$3,328	$3,291	$2,695
Charger	IC	All	2008/2010	$521	$437	$437	$370	$370	$370	$370	$370	$272
Charger Labor	IC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010

Table 3-60 NHTSA Costs for EV100 Applied in Volpe Model with No Mass Reduction (2010$)

Tech.	Cost Type	NHTSA Vehicle Class	Baseline Fleet	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$12,341	$9,873	$9,873	$7,898	$7,898	$7,898	$7,898	$7,898	$6,319
			2008	$12,063	$9,651	$9,651	$7,720	$7,720	$7,720	$7,720	$7,720	$6,176
Battery	DMC	Midsize PC/Perf PC	2010	$14,159	$11,327	$11,327	$9,062	$9,062	$9,062	$9,062	$9,062	$7,250
			2008	$13,919	$11,135	$11,135	$8,908	$8,908	$8,908	$8,908	$8,908	$7,127

Battery	DMC	Large PC/Perf PC	2010	$17,482	$13,985	$13,985	$11,188	$11,188	$11,188	$11,188	$11,188	$8,951
			2008	$17,025	$13,620	$13,620	$10,896	$10,896	$10,896	$10,896	$10,896	$8,717
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$410	$398	$386	$375	$363	$352	$345	$338	$332
			2008	$354	$343	$333	$323	$313	$304	$298	$292	$286
Non-battery	DMC	Midsize PC/Perf PC	2010	$1,267	$1,229	$1,193	$1,157	$1,122	$1,088	$1,067	$1,045	$1,024
			2008	$1,156	$1,122	$1,088	$1,055	$1,024	$993	$973	$954	$935
Non-battery	DMC	Large PC/Perf PC	2010	$2,236	$2,169	$2,104	$2,041	$1,980	$1,920	$1,882	$1,844	$1,808
			2008	$2,080	$2,018	$1,957	$1,899	$1,842	$1,786	$1,751	$1,716	$1,681
Charger	DMC	All	2008/2010	$395	$316	$316	$253	$253	$253	$253	$253	$202
Charger Labor	DMC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$5,309	$5,127	$5,127	$4,982	$4,982	$4,982	$4,982	$4,982	$3,138
			2008	$5,189	$5,012	$5,012	$4,870	$4,870	$4,870	$4,870	$4,870	$3,067
Battery	IC	Midsize PC/Perf PC	2010	$6,091	$5,883	$5,883	$5,716	$5,716	$5,716	$5,716	$5,716	$3,600
			2008	$5,988	$5,783	$5,783	$5,619	$5,619	$5,619	$5,619	$5,619	$3,539
Battery	IC	Large PC/Perf PC	2010	$7,520	$7,263	$7,263	$7,057	$7,057	$7,057	$7,057	$7,057	$4,445
			2008	$7,324	$7,073	$7,073	$6,873	$6,873	$6,873	$6,873	$6,873	$4,329
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$316	$315	$314	$313	$313	$312	$311	$311	$200
			2008	$272	$272	$271	$270	$269	$269	$268	$268	$172
Non-battery	DMC	Midsize PC/Perf PC	2010	$976	$973	$970	$968	$965	$963	$961	$960	$618
			2008	$890	$888	$885	$883	$881	$878	$877	$876	$563
Non-battery	DMC	Large PC/Perf PC	2010	$1,722	$1,717	$1,712	$1,708	$1,703	$1,699	$1,696	$1,693	$1,090
			2008	$1,602	$1,597	$1,593	$1,588	$1,584	$1,580	$1,578	$1,575	$1,014
Charger	IC	All	2008/2010	$126	$121	$121	$117	$117	$117	$117	$117	$70
Charger Labor	IC	All	2008/2010	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$17,650	$15,000	$15,000	$12,880	$12,880	$12,880	$12,880	$12,880	$9,457
			2008	$17,253	$14,662	$14,662	$12,590	$12,590	$12,590	$12,590	$12,590	$9,244
Battery	TC	Midsize PC/Perf PC	2010	$20,250	$17,210	$17,210	$14,778	$14,778	$14,778	$14,778	$14,778	$10,850
			2008	$19,907	$16,918	$16,918	$14,527	$14,527	$14,527	$14,527	$14,527	$10,666
Battery	TC	Large PC/Perf PC	2010	$25,002	$21,248	$21,248	$18,245	$18,245	$18,245	$18,245	$18,245	$13,396
			2008	$24,349	$20,693	$20,693	$17,769	$17,769	$17,769	$17,769	$17,769	$13,046
Non-battery	TC	Subcompact PC/Perf PC Compact	2010	$726	$713	$700	$688	$676	$664	$657	$649	$532

		PC/Perf PC	2008	$626	$615	$603	$593	$582	$572	$566	$559	$458
Non-battery	TC	Midsize PC/Perf PC	2010	$2,243	$2,203	$2,163	$2,125	$2,087	$2,051	$2,028	$2,005	$1,642
			2008	$2,047	$2,010	$1,973	$1,938	$1,904	$1,871	$1,850	$1,829	$1,498
Non-battery	TC	Large PC/Perf PC	2010	$3,959	$3,887	$3,817	$3,749	$3,683	$3,619	$3,578	$3,538	$2,897
			2008	$3,682	$3,615	$3,550	$3,487	$3,426	$3,367	$3,328	$3,291	$2,695
Charger	IC	All	2008/2010	$521	$437	$437	$370	$370	$370	$370	$370	$272
Charger Labor	IC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010

Table 3-61 NHTSA Costs for EV150 Applied in Volpe Model with No Mass Reduction (2010$)

Tech.	Cost Type	NHTSA Vehicle Class	Baseline Fleet	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$16,369	$13,095	$13,095	$10,476	$10,476	$10,476	$10,476	$10,476	$8,381
			2008	$15,939	$12,751	$12,751	$10,201	$10,201	$10,201	$10,201	$10,201	$8,161
Battery	DMC	Midsize PC/Perf PC	2010	$19,585	$15,668	$15,668	$12,534	$12,534	$12,534	$12,534	$12,534	$10,028
			2008	$19,240	$15,392	$15,392	$12,313	$12,313	$12,313	$12,313	$12,313	$9,851
Battery	DMC	Large PC/Perf PC	2010	$22,552	$18,042	$18,042	$14,433	$14,433	$14,433	$14,433	$14,433	$11,547
			2008	$21,936	$17,549	$17,549	$14,039	$14,039	$14,039	$14,039	$14,039	$11,231
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$410	$398	$386	$375	$363	$352	$345	$338	$332
			2008	$355	$344	$334	$324	$314	$305	$299	$293	$287
Non-battery	DMC	Midsize PC/Perf PC	2010	$1,267	$1,229	$1,193	$1,157	$1,122	$1,088	$1,067	$1,045	$1,024
			2008	$1,157	$1,123	$1,089	$1,056	$1,025	$994	$974	$954	$935
Non-battery	DMC	Large PC/Perf PC	2010	$2,236	$2,169	$2,104	$2,041	$1,980	$1,920	$1,882	$1,844	$1,808
			2008	$2,082	$2,019	$1,959	$1,900	$1,843	$1,788	$1,752	$1,717	$1,682
Charger	DMC	All	2008/2010	$395	$316	$316	$253	$253	$253	$253	$253	$202
Charger Labor	DMC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$7,042	$6,801	$6,801	$6,608	$6,608	$6,608	$6,608	$6,608	$4,162
			2008	$6,857	$6,622	$6,622	$6,434	$6,434	$6,434	$6,434	$6,434	$4,053
Battery	IC	Midsize PC/Perf PC	2010	$8,425	$8,137	$8,137	$7,906	$7,906	$7,906	$7,906	$7,906	$4,980
			2008	$8,277	$7,993	$7,993	$7,767	$7,767	$7,767	$7,767	$7,767	$4,892
Battery	IC	Large	2010	$9,702	$9,370	$9,370	$9,104	$9,104	$9,104	$9,104	$9,104	$5,734

		PC/Perf PC	2008	$9,437	$9,114	$9,114	$8,855	$8,855	$8,855	$8,855	$8,855	$5,578
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$316	$315	$314	$313	$313	$312	$311	$311	$200
			2008	$273	$273	$272	$271	$270	$270	$269	$269	$173
Non-battery	DMC	Midsize PC/Perf PC	2010	$976	$973	$970	$968	$965	$963	$961	$960	$618
			2008	$891	$889	$886	$884	$881	$879	$878	$876	$564
Non-battery	DMC	Large PC/Perf PC	2010	$1,722	$1,717	$1,712	$1,708	$1,703	$1,699	$1,696	$1,693	$1,090
			2008	$1,603	$1,598	$1,594	$1,590	$1,585	$1,581	$1,579	$1,576	$1,014
Charger	IC	All	2008/2010	$126	$121	$121	$117	$117	$117	$117	$117	$70
Charger Labor	IC	All	2008/2010	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$23,411	$19,896	$19,896	$17,084	$17,084	$17,084	$17,084	$17,084	$12,543
			2008	$22,796	$19,373	$19,373	$16,635	$16,635	$16,635	$16,635	$16,635	$12,214
Battery	TC	Midsize PC/Perf PC	2010	$28,010	$23,805	$23,805	$20,441	$20,441	$20,441	$20,441	$20,441	$15,007
			2008	$27,517	$23,385	$23,385	$20,080	$20,080	$20,080	$20,080	$20,080	$14,743
Battery	TC	Large PC/Perf PC	2010	$32,254	$27,411	$27,411	$23,537	$23,537	$23,537	$23,537	$23,537	$17,281
			2008	$31,372	$26,662	$26,662	$22,894	$22,894	$22,894	$22,894	$22,894	$16,809
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	2010	$726	$713	$700	$688	$676	$664	$657	$649	$532
			2008	$628	$617	$606	$595	$585	$574	$568	$561	$460
Non-battery	TC	Midsize PC/Perf PC	2010	$2,243	$2,203	$2,163	$2,125	$2,087	$2,051	$2,028	$2,005	$1,642
			2008	$2,048	$2,011	$1,975	$1,940	$1,906	$1,873	$1,852	$1,831	$1,499
Non-battery	TC	Large PC/Perf PC	2010	$3,959	$3,887	$3,817	$3,749	$3,683	$3,619	$3,578	$3,538	$2,897
			2008	$3,685	$3,618	$3,552	$3,489	$3,428	$3,369	$3,330	$3,293	$2,697
Charger	IC	All	2008/2010	$521	$437	$437	$370	$370	$370	$370	$370	$272
Charger Labor	IC	All	2008/2010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010	$1,010

3.4.3.6.6 Fuel cell electric vehicles

Fuel cell electric vehicles (FCEVs) – utilize a full electric drive platform but consume electricity generated by an on-board fuel cell and hydrogen fuel. Fuel cells are electro-chemical devices that directly convert reactants (hydrogen and oxygen via air) into electricity, with the potential of achieving more than twice the efficiency of conventional internal combustion engines. High pressure gaseous hydrogen storage tanks are used by most automakers for FCEVs that are currently under development. The high pressure tanks are similar to those used for compressed gas storage in more than 10 million CNG vehicles worldwide, except that they are designed to operate at a higher pressure (350 bar or 700 bar vs. 250 bar for CNG). Due to the uncertainty of the future availability for this technology, FCEVs were not included in any OMEGA or Volpe model runs.

3.4.3.7 Batteries for Mild HEV, HEV, PHEV and EV Applications

The design of battery secondary cells can vary considerably between Stop/Start, Mild HEV (ISG), HEV, PHEV and EV applications.

MHEV batteries: Due to their lower voltage (12-42 VDC) and reduced power and energy requirements, MHEV systems may continue to use lead-acid batteries even long term (2017 model year and later). MHEV battery designs differ from those of current starved-electrolyte (typical maintenance free batteries) or flooded-electrolyte (the older style lead-acid batteries requiring water "top-off") batteries used for starting, lighting and ignition (SLI) in automotive applications. Standard SLI batteries are primarily designed to provide high-current for engine start-up and then recharge immediately after startup via the vehicle's charging system. Deeply discharging a standard SLI battery will greatly shorten its life. MHEV applications are expected to use:

- Extended-cycle-life flooded (ELF) lead-acid batteries
- Absorptive glass matt, valve-regulated lead-acid (AGM/VRLA) batteries –or –
- Asymmetric lead-acid battery/capacitor hybrids (*e.g.*, flooded ultrabatteries)

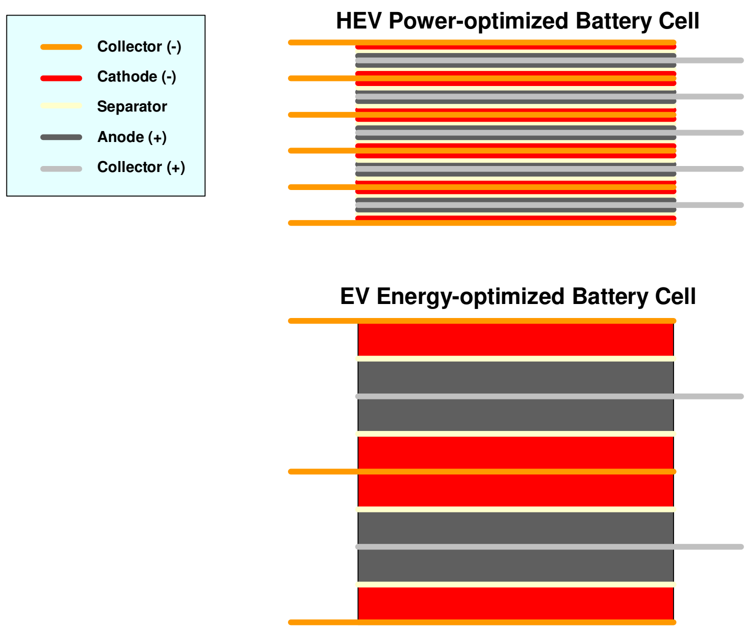
MHEV systems using electrolytic double-layer capacitors are also under development and may provide improved performance and reduced cost in the post-2017 timeframe.

Mild HEV and HEV batteries: Mild HEV and HEV applications operate in a narrow, short-cycling, charge-sustaining state of charge (SOC). Energy capacity in Mild HEV and HEV applications is somewhat limited by the ability of the battery and power electronics to accept charge and by space and weight constraints within the vehicle design. Mild HEV and HEV battery designs tend to be optimized for high power density rather than high energy density, with thinner cathode and anode layers and more numerous current collectors and separators (Figure 3-20).

EV batteries: EV batteries tend to be optimized for high energy density and are considerably larger and heavier than HEV batteries in order to provide sufficient energy capacity. EV battery cells tend to have thicker cathode and anode layers and fewer collectors and separators than HEV cells. This reduces the specific cost on a per-kWh basis for EV battery cells relative to HEV battery cells.

PHEV batteries: PHEV battery designs are intermediate between power-optimized HEV and energy-optimized EV battery cell designs. PHEV batteries must provide both charge depleting operation similar to an EV and charge sustaining operation similar to an HEV. Unlike HEV applications, charge-sustaining operation with PHEVs occurs at a relatively low battery state of charge (SOC) which can pose a significant challenge with respect to attaining acceptable battery cycle life. In the case of the GM Volt, this limits charge depleting operation to a minimum SOC of approximately 30 percent.[59] An alternative approach for PHEV applications that has potential to allow extension of charge depletion to a lower battery SOC is using energy-optimized lithium-ion batteries for charge depleting operation in combination with the use of supercapacitors or power-optimized batteries for charge sustaining operation.[60]

Figure 3-20: Schematic representation of power and energy optimized prismatic-layered battery cells



Power-split hybrid vehicles from Toyota, Ford and Nissan, integrated motor assist hybrid vehicles from Honda and the GM 2-mode hybrid vehicles currently use nickel-metal hydride (NiMH) batteries. Lithium-ion (Li-ion) batteries offer the potential to approximately double both the energy and power density relative to current NiMH batteries, enabling much more electrification of automotive drive applications such as PHEVs and EVs.

Li-ion batteries for high-volume automotive applications differ substantially from those used in consumer electronics applications with respect to cathode chemistry, construction and cell size. Li-ion battery designs currently in production by CPI (LG-Chem) for the GM Volt PHEV and by AESC and GS-Yuasa (respectively) for the Nissan Leaf and Mitsubishi iMiEV use large-format, layered-prismatic cells assembled into battery modules. The modules are then combined into battery packs.

Two families of cathode chemistries are used in large-format, automotive Li-ion batteries currently in production – LiMn2O4-spinel (CPI, GS-Yuasa, AESC) and LiFePO4 (A123 Systems). Current production batteries typically use graphite anodes. Automotive Li-ion batteries using lithium nickel manganese cobalt (NMC) oxide cathodes with graphite anodes are in advanced stages of development for PHEV and EV applications. The agencies expect large-format Li-ion batteries to completely replace NiMH batteries for post-2017 HEV applications. We also expect that stacked and/or folded prismatic Li-ion cell designs will continue to be used for PHEV and EV applications and that NMC/graphite Li-ion batteries will be a mature technology for 2017-2025 light-duty vehicle applications.

3.4.3.8 HEV, PHEV and EV System Sizing Methodology

Battery packs are (and will continue to be) one of the most expensive components for EVs, PHEVs and HEVs. To obtain reasonable cost estimates for electrified vehicles, it was therefore important to establish a reliable approach for determining battery attributes for each vehicle and class. Both battery energy content ("size") and power rating are key inputs used to establish costs per ANL's battery costing model. For EVs and PHEVs in particular, battery size and weight are closely related, and so battery weight must be known as well. The following section details the steps taken to size a battery for

a) EVs and PHEVs (at various all-electric ranges),
b) a more simplified separate approach for MHEVs and HEVs.

3.4.3.8.1 Battery Pack Sizing for EVs and PHEVs

Calculation of required battery pack energy requirements for EVs and PHEVs is not straightforward. Because vehicle energy consumption is strongly dependent on weight, and battery packs are very heavy, the weight of the battery pack itself can change the energy required to move the vehicle. As vehicle energy consumption increases, the battery size must increase for a given range (in the case of EVs and PHEVs) – as a result, vehicle weight increases, and per-mile energy consumption increases as well, increasing the battery size, and so on.

EPA built spreadsheets to estimate the required battery size for each vehicle and class. Listed below are the steps EPA has taken in these spreadsheets to estimate not only battery size, but associated weight for EVs and PHEVs of varying ranges and designs.

1. Establish baseline FE/energy consumption
2. Assume nominal weight of electrified vehicle (based on weight reduction target)
3. Calculate vehicle energy demand at this target weight
4. Calculate required battery energy
5. Calculate actual battery and vehicle weight
6. Do vehicle weight and battery size match estimated values?

Steps 2-6 were iterated until each assumed weight reduction target (and nominal vehicle weight) reconciled with required battery size and the calculated weight of each vehicle.

Baseline vehicle energy consumption is estimated based on a fitted trendline for FE vs. inertia weight, or ETW (from FE Trends data for 2008 MY vehicles, table M-80) and converting to Wh/mi. This is shown in Figure 3-21.

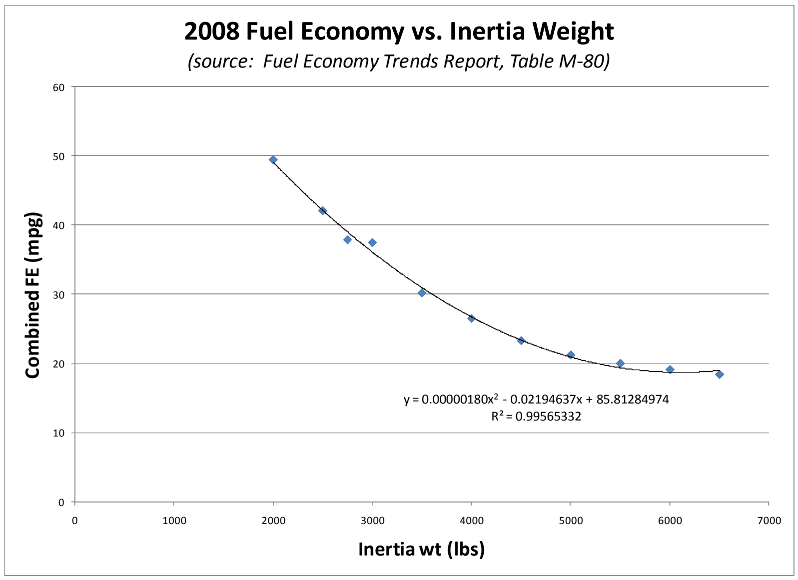


Figure 3-21: Average fuel economy based on inertia weight (ETW) from FE Trends data

Then, fuel economy was converted into energy consumption (assuming 33700 Wh energy in 1 gallon of gasoline) and used to populate a range of test weights between 2000 and 6000 lbs. A linear trendline was used to fit this curve and then applied to estimate generic energy consumption for baseline vehicles of a given ETW (shown below in Figure 3-22).

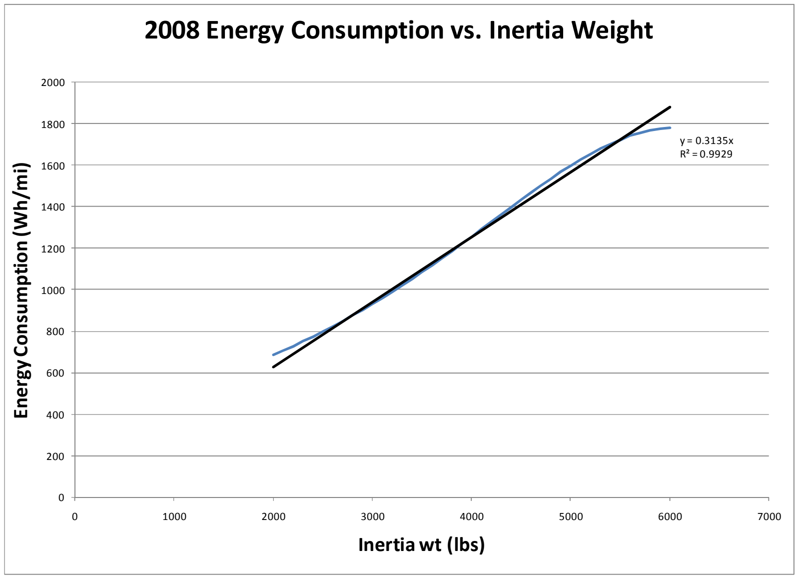


Figure 3-22: Equivalent energy consumption (in Wh/mi) for baseline vehicles

To calculate battery pack size, the electrified vehicle weight must first be known; to calculate vehicle weight, the battery pack size must first be known. This circular reference required an iterative solution. EPA assumed a target vehicle glider (a rolling chassis with no powertrain) weight reduction and applied that to the baseline curb weight. The resulting nominal vehicle weight was then used to calculate the vehicle energy demand. To calculate the energy demand (efficiency) of an electric vehicle in Wh/mi, the following information was needed:

- Baseline energy consumption / mpg
- Efficiency (η) improvement of electric vehicle
- Change in road loads

In Table 3-62 below, the following definitions apply:

- Brake eff (brake efficiency) – the % amount of chemical fuel energy converted to energy at the engine crankshaft (or, for batteries, the amount of stored electrical energy converted to shaft energy entering the transmission)
- D/L eff (driveline efficiency) – the % of the brake energy entering the transmission delivered through the driveline to the wheels
- Wheel eff (wheel efficiency) – the product of brake and driveline efficiency
- Cycle eff (cycle efficiency) – the % of energy delivered to the wheels used to overcome road loads and power the vehicle (it does not include energy lost as braking heat)
- Vehicle efficiency – the product of wheel and cycle efficiency

- Road loads – the amount of resistant energy the vehicle must overcome during a city/highway test. Composed of vehicle weight (inertia), aerodynamic drag and rolling resistance

Table 3-62: EV100 efficiency and energy demand calculations, 20% applied weight reduction

Class	Brake eff	D/L eff	Wheel eff	Cycle eff	Vehicle eff	Road loads	Energy reduction	Energy eff increase	IW-based, base ICE nominal mpgge	Base fuel energy req'd Wh/mi	FTP fuel energy req'd Wh/mi	Onroad fuel energy req'd Wh/mi
Baseline gas ICE	24%	81%	20%	77%	15%	100%						
Small car	85%	93%	79%	97%	77%	88%	83%	478%	37	912	158	225
Std car	85%	93%	79%	97%	77%	88%	83%	478%	30	1122	194	277
Large car	85%	93%	79%	97%	77%	88%	83%	478%	25	1332	230	329
Small MPV	85%	93%	79%	97%	77%	89%	83%	475%	29	1180	205	293
Large MPV	85%	93%	79%	97%	77%	89%	83%	475%	23	1497	260	372
Truck	85%	93%	79%	97%	77%	88%	83%	482%	20	1727	297	424

The energy efficiency of a baseline vehicle (around 15%), as indicated in the table above, was estimated using efficiency terms derived from EPA's lumped parameter model (engine/battery brake efficiency, driveline efficiency, cycle efficiency and road load ratio to baseline). To calculate the energy consumption of an EV (or PHEV in charge-depleting mode), the following assumptions were made:

- "Brake" efficiency (for an EV, the efficiency of converting battery energy to tractive energy at the transmission input shaft) was estimated at 85% - assuming, roughly a 95% efficiency for the battery, motor, and power electronics, respectively.

- The driveline efficiency (including the transmission) was comparable to the value calculated by the lumped parameter model for an advanced 6-speed dual-clutch transmission at 93%.

- The cycle efficiency assumes regenerative braking where 97% recoverable braking energy is recaptured. As a result, most of the energy delivered to the wheels is used to overcome road loads.

- The road loads were based on the weight reduction of the vehicle. In the case of a 100 mile EV with a 20% weight reduction, road loads (as calculated by the LP model) are reduced to 88-89% of the baseline vehicle[vv].

[vv] Included in this example road load calculation is a 10% reduction in rolling resistance and aerodynamic drag.

The energy consumption of the EV includes ratio of the roadloads of the EV to the baseline vehicle, and the ratio of the efficiency of the EV compared to the baseline vehicle. It is expressed mathematically as shown below in Equation 3-1: EV energy consumption:

Equation 3-1: EV energy consumption

$$E_{EV\_FTP}(Wh/mi) = E_{baseline\_FTP} * \left(\frac{\%Roadload_{new}}{\%Roadload_{old}} * \frac{\eta_{vehicle\_old}}{\eta_{vehicle\_new}}\right)$$

In Table 3-63, the baseline energy required (in Wh/mi) is in the column labeled "Base fuel energy reqd". The energy required for each vehicle class EV over the FTP is in the column "FTP fuel energy reqd Wh/mi" and incorporates the equation above. This energy rate refers to the laboratory or unadjusted test cycle value, as opposed to a real-world "onroad" value. EPA assumes a 30% fuel economy shortfall, based loosely on the 5-cycle Fuel Economy Labeling Rule (year) which is directionally correct for electrified vehicles. This corresponds to an increase in fuel consumption of 43%. Applying this 43% increase gives the onroad energy consumption values for EVs as shown in the far right column of the previous table. From this value, one can determine an appropriate battery pack size for the vehicle.

The required battery energy for EVs equals the onroad energy consumption, multiplied by the desired range, divided by the useful state-of-charge window of the battery. It is calculated as follows in Equation 3-2

Equation 3-2: Required battery pack energy (size) for EVs

$$BP(kWh) = \frac{E_{onroad}(\frac{Wh}{mi}) \times range(mi)}{SOC\%}$$

Assumed usable SOC (battery state-of-charge) windows were 80% for EVs (10-90%) and 70% for PHEVs (15%-85%). The battery pack sizes are listed in orange in Table 3-63 for the 100-mile EV case and show both the onroad energy consumption ("EV adj Wh/mi" column) and the nominal battery energy content or "battery pack size".

Table 3-63: Battery pack sizes for EV100 based on inertia weight, 20% applied weight reduction

Class	Baseline curb wt (lb)	Inertia wt (lb)	EV unadj (Wh/mi)	EV adj (Wh/mi)	100 mile batt pack size (kWh)
2008 Baseline					
Small car	2633	2933	158	225	28.2
Std car	3306	3606	194	277	34.7
Large car	3897	4197	230	329	41.1
Small MPV	3474	3774	205	293	36.7
Large MPV	4351	4651	260	372	46.5
Truck	5108	5408	297	424	53.0
2010 Baseline					
Small car	2753	3053	164	234	29.2
Std car	3387	3687	200	286	35.7
Large car	4035	4335	241	344	43.0
Small MPV	3528	3828	209	298	37.3
Large MPV	4313	4613	257	367	45.8
Truck	5346	5646	307	439	54.8

EPA used the following formula to determine weight of an EV (Equation 3-3):

Equation 3-3: EV weight calculation

$$W_{EV} = W_{base} - WR_{glider} - W_{ICE\_powertrain} + W_{electric\_drive}$$

Any weight reduction technology was applied only to the glider (baseline vehicle absent powertrain) as defined in Equation 3-4.

Equation 3-4: Weight reduction of the glider

$$WR_{glider} = \%WR * (W_{base} - W_{ICE\_powertrain})$$

In the case of a PHEV, it was assumed that the base ICE powertrain remains so it is not deducted; the proper equation for PHEVs is shown in Equation 3-5.

Equation 3-5: Weight calculation for PHEV

$$W_{PHEV} = W_{base} - WR_{glider} + W_{electric\_drive}$$

Listed in Table 3-64 are the assumed baseline ICE-powertrain weights, by vehicle class:

Table 3-64: Baseline ICE-powertrain weight assumptions, by class

Class	Engine	Trans (diff not included)	Fuel sys (50% fill)	Engine mounts/ NVH treatments	Exhaust	12V batt	Total ICE powertrain weight
Small car	250	125	50	25	20	25	495
Std car	300	150	60	25	25	30	590
Large car	375	175	70	25	30	35	710
Small MPV	300	150	60	25	25	30	590
Large MPV	400	200	80	25	30	40	775
Truck	550	200	100	25	40	50	965

EPA then estimated the weight of the electric drive subsystem using the energy content of the battery pack as an input. EPA scaled the weight by applying a specific energy for the electric drive subsystem–including the battery pack, drive motor, wiring, power electronics, etc.–of 120 Wh/kg (or 18.33 lb/kWh). This specific energy value is based on adding components to an assumed battery pack specific energy of 150 Wh/kg[ww]. Then, the gearbox (the only subsystem excluded from the electric drive scaling) was added to the weight of the electric drive subsystem; this total was included into the electric vehicle weight calculation as $W_{electric\_drive}$[xx]. A summary table of electric drive weights for 100-mile EVs is shown as Table 3-65.

[ww] 150 Wh/kg is a conservative estimate for year 2017 and beyond: outputs from ANL's battery cost model, which shows specific energy values of 160- 180 Wh/kg for a similar timeframe.

[xx] Applies only to the EV. Because the baseline ICE powertrain weight (which includes gearbox weight) was not deducted from the PHEV, it is not added back in for the PHEV.

Table 3-65: Total electric drive weights for 100-mile EVs

Class	Batt pack size (kWh)	2020 electric content (lbs)	Gearbox (power-split or other)	2020 EV powertrain total
2008 Baseline				
Small car	28.2	517	50	567
Std car	34.7	635	60	695
Large car	41.1	754	70	824
Small MPV	36.7	672	60	732
Large MPV	46.5	853	80	933
Truck	53.0	972	100	1072
2010 Baseline				
Small car	29.2	536	50	586
Std car	35.7	655	60	715
Large car	43.0	788	70	858
Small MPV	37.3	683	60	743
Large MPV	45.8	840	80	920
Truck	54.8	1005	100	1105

The difference between the actual weight and the predicted or nominal weight should be zero. However, if not then a revised weight reduction was used for another iteration of steps 2-6 until the two vehicle weights match. Spreadsheet tools such as "solver" in MS Excel were used for automating this iterative process.

Table 3-66 shows example results for 100-mile range EVs; in this case a 20% applied glider weight reduction for a variety of vehicle classes.

Table 3-66: Sample calculation sheet for 100-mile EVs for the 2008 Baseline

Class	Base curb wt (lb)	Base power/wt ratio	Powertrain weight (lb)	Base glider wt (lb)	WR of glider	New EV wt (nominal lb)	Energy cons adjusted (Wh/mi)	Batt pack size (kWh)	Electric drive wt (lb)	New EV weight (lb)	Error	% WR from curb	% RL vs base
Small car	2633	0.0486	495	2138	428	2205	225	28.2	567	2277	0	13.5%	88%
Std car	3306	0.0575	590	2716	543	2763	277	34.7	695	2868	0	13.2%	88%
Large car	3897	0.0872	710	3187	637	3260	329	41.1	824	3374	0	13.4%	88%
Small MPV	3474	0.0463	590	2884	577	2897	293	36.7	732	3039	0	12.5%	89%
Large MPV	4351	0.0565	775	3576	715	3636	372	46.5	933	3794	0	12.8%	89%
Truck	5108	0.0617	965	4143	829	4279	424	53.0	1072	4387	0	14.1%	88%

Table 3-67 shows the effect on net electric vehicle weight reduction after 20% glider weight reduction was applied to EVs and PHEVs. As battery pack size increases for larger-range EVs and PHEVs, the overall realized vehicle weight reduction decreases (because it requires more energy to carry the extra battery weight). In this example, EVs with a 150 mile range require almost 20% weight reduction to the glider to make up for the additional weight of the electric drive and battery pack compared to a conventional ICE-based powertrain.

Table 3-67: Actual weight reduction percentages for EVs and PHEVs with 20% weight reduction applied to glider

	75 Mile EV Actual %WR vs. base vehicle	100 Mile EV Actual %WR vs. base vehicle	150 Mile EV Actual %WR vs. base vehicle	20 Mile PHEV Actual %WR vs. base vehicle	40 Mile PHEV Actual %WR vs. base vehicle
2008 Baseline					
Small car	19%	14%	2%	12%	7%
Standard car	18%	13%	2%	12%	7%
Large car	19%	13%	2%	12%	7%
Small MPV	18%	13%	1%	12%	7%
Large MPV	18%	13%	1%	12%	7%
Truck	19%	14%	3%	11%	6%
2010 Baseline					
Small car	18%	13%	1%	12%	7%
Standard car	18%	13%	1%	12%	7%
Large car	18%	13%	1%	12%	7%
Small MPV	18%	12%	1%	12%	8%
Large MPV	18%	13%	1%	12%	7%
Truck	19%	14%	3%	11%	6%

Because there is no "all-electric range" requirement for HEVs, battery pack sizes were relatively consistent for a given weight class. Furthermore, because battery pack sizes are at least an order of magnitude smaller for HEVs than for all-electric vehicles, the sensitivity of HEV vehicle weight (and hence energy consumption) to battery pack size is rather insignificant. For these reasons, a more direct approach (rather than an iterative process) works for battery sizing of HEVs.

- HEV batteries were scaled similar to the 2010 Fusion Hybrid based on nominal battery energy per lb ETW (equivalent test weight), at 0.37 Wh/lb.

- A higher usable SOC window of 40% (compared to 30% for Fusion Hybrid) reduced the required Li-Ion battery size to 75% of the Fusion Hybrid's NiMH battery. This resulted in a 0.28 Wh/lb ETW ratio.

- In comparing anecdotal data for HEVs, the agencies assumed a slight weight increase of 4-5% for HEVs compared to baseline non-hybridized vehicles. The added weight of the Li-ion pack, motor and other electric hardware were offset partially by the reduced size of the base engine.

3.4.3.9 HEV, PHEV and EV battery pack design and cost analysis using the ANL BatPaC model

The U.S. Department of Energy (DOE) has established long term industry goals and targets for advanced battery systems as it does for many energy efficient technologies. Argonne National Laboratory (ANL) was funded by DOE to provide an independent assessment of Li-ion battery costs because of their expertise in the field as one of the primary

DOE National Laboratories responsible for basic and applied battery energy storage technologies for future HEV, PHEV and EV applications. A basic description of the ANL Li-ion battery cost model and initial modeling results for PHEV applications were published in a peer-reviewed technical paper presented at EVS-24[61]. ANL has extended modeling inputs and pack design criteria within the battery cost model to include analysis of manufacturing costs for EVs and HEVs as well has PHEVs.[62] In early 2011, ANL issued a draft report detailing the methodology, inputs and outputs of their Battery Performance and Cost (BatPaC) model.[63] A complete independent peer-review of the BatPaC model and its inputs and results for HEV, PHEV and EV applications has been completed[64]. ANL recently provided the agencies with an updated report documenting the BatPaC model that fully addresses the issues raised within the peer review.[65] Based on the feedback from peer-reviewers, ANL updated the model in the following areas.

1. Battery pack cost is adjusted upward. This adjustment is based on the feedback from several peer-reviewers, and changes are related to limiting electrode thickness to 100 microns, changing allocation of overhead cost to more closely represent a Tier 1 auto supplier, increasing cost of tabs, changing capital cost of material preparation, etc;
2. Battery management system cost is increased to represent the complete monitoring and control needs for proper battery operation and safety as shown in Table 5.3 in the report;
3. Battery automatic and manual disconnect unit cost is added based on safety considerations as shown in Table 5.3 in the report;
4. Liquid thermal management system is added. ANL stated in the report that the liquid-cooled closure design it uses in the model would not have sufficient surface area and cell spacing to be cooled by air effectively as shown in Table 5.3 in the report.

Subsequently, the agencies requested that an option be added to select between liquid or air thermal management and that adequate surface area and cell spacing be determined accordingly. Also, the agencies requested a feature to allow battery packs to be configured as subpacks in parallel or modules in parallel, as additional options for staying within voltage and cell size limits for large packs.

ANL added these features in a version of the model distributed March 1, 2012. This version of the model is used for the battery cost estimates in the final rule. This model and the peer review report are available in the public dockets for this rulemaking.[64,66]

NHTSA and EPA decided to use the ANL BatPaC model for estimating large-format lithium-ion batteries for this final rule, consistent with the proposal, for the following reasons. First, the ANL model has been described and presented in the public domain and does not rely upon confidential business information (which would therefore not be reviewable by the public). The model was developed by scientists at ANL who have significant experience in this area. The model uses a bill of materials methodology which the agencies believe is the preferred method for developing cost estimates. The ANL model appropriately considers the vehicle applications power and energy requirements, which are two of the fundamental parameters when designing a lithium-ion battery for an HEV, PHEV, or EV. The ANL model can estimate high volume production costs, which the agencies believe is appropriate for the 2025 time frame. Finally, the ANL model's cost estimates, while generally lower than the estimates we received from the OEMs, is consistent with some of the supplier cost estimates the agencies received from large-format lithium-ion battery pack manufacturers. A portion of those data was received from on-site visits to vehicle manufacturers and battery suppliers done by the EPA in 2008.

The ANL battery cost model is based on a bill of materials approach in addition to specific design criteria for the intended application of a battery pack. The costs include materials, manufacturing processes, the cost of capital equipment, plant area, and labor for each manufacturing step as well as the design criteria include a vehicle application's power and energy storage capacity requirements, the battery's cathode and anode chemistry, and the number of cells per module and modules per battery pack. The model assumes use of a laminated multi-layer prismatic cell and battery modules consisting of double-seamed rigid containers. The model also assumes that the battery modules are liquid-cooled. The model takes into consideration the cost of capital equipment, plant area and labor for each step in the manufacturing process for battery packs and places relevant limits on electrode coating thicknesses and other processes limited by existing and near-term manufacturing processes. The ANL model also takes into consideration annual pack production volume and economies of scale for high-volume production.

Basic user inputs to BatPaC include performance goals (power and energy capacity), choice of battery chemistry (of five predefined chemistries), the vehicle type for which the battery is intended (HEV, PHEV, or EV), the desired number of cells and modules, and the volume of production. BatPaC then designs the cells, modules, and battery pack, and provides an itemized cost breakdown at the specified production volume.

BatPaC provides default values for engineering properties and material costs that allow the model to operate without requiring the user to supply detailed technical or experimental data. In general, the default properties and costs represent what the model authors consider to be reasonable values representing the state of the art expected to be available to large battery manufacturers in the year 2020. Users are encouraged to change these defaults as necessary to represent their own expectations or their own proprietary data.

In using BatPaC, it is extremely important that the user monitor certain properties of the cells, modules, and packs that it generates, to ensure that they stay within practical design guidelines, adjusting related inputs if necessary. In particular, pack voltage and individual cell capacity should be limited to appropriate ranges for the application. These design guidelines are not rigidly defined but approximate ranges are beginning to emerge in the industry.

Also inherent in BatPaC are certain modeling assumptions that are still open to some uncertainty or debate in the industry. For some, such as the available portion of total battery energy (aka "SOC window") for a PHEV/EV/HEV, the user can easily modify a single parameter to represent a value other than the default. For others, such as specific unit costs for thermal management or battery monitoring components, changes can often be made by replacing the relevant components of the model outputs.

The cost outputs used by the agencies to determine 2025 HEV, PHEV and EV battery costs were based on the following inputs and assumptions.

EPA selected basic user inputs as follows. For performance goals, EPA used the power and energy requirements derived from the scaling analysis described in the previous section. Specifically, these covered each of the six classes of vehicles (Small Car, Standard Car, Large Car, Small MPV, Large MPV and Truck) under each of the five weight reduction scenarios (0%, 2%, 7.5%, 10%, and 20%). The chosen battery chemistries were NMC441-G (for EVs and PHEV40) and LMO-G (for P2 HEVs and PHEV20). Vehicle types were EV75, EV100, EV150 (using the BatPaC "EV" setting); PHEV20 and PHEV40 (using the "PHEV" setting), and P2 HEV (using the "HEV-HP" setting). All modules were composed of 32 cells, with each pack having a varying number of modules. Cost outputs were generated for annual production volumes of 50K, 125K, 250K, and 450K packs. The cost outputs for the 450K production volume are used in the FRM analysis, consistent with the proposal, as being applicable in MY 2017 (HEVs) and MY 2025 (EVs and PHEVs).

For engineering properties and material costs, and for other parameters not identified below, EPA used the defaults provided in the model.

For design guidelines regarding pack voltage and cell capacity, EPA chose guidelines based on knowledge of current practices and developing trends of battery manufacturers and OEMs, supplemented by discussions with the BatPaC authors. Specifically: (1) allowable pack voltage was targeted to approximately 120V for HEVs and approximately 350-400V for EVs and PHEVs (with some EV150 packs for larger vehicles allowed to about 460-600V); (2) allowable cell capacity was limited to less than approximately 80 A-hr.

EPA made several modeling assumptions that differed from the default model: (1) The SOC window for HEVs was increased to 40% rather than the default 25%. (2) HEV packs were modeled as air cooled instead of liquid cooled (except for Truck and MPV with Towing, which are modeled as liquid-cooled). EPA replaced the model's projected costs for air cooling components (blower motor, ducting, and temperature feedback) with costs derived from FEV's teardown studies, which may be more representative of volume production than the default values provided in the model.

Additionally, EPA did not include warranty costs computed by BatPaC in the total battery cost because these are accounted for elsewhere by means of indirect cost multipliers (ICMs).

Table 3-68 Summary of Inputs and Assumptions Used with BatPaC

Category of	BatPaC Default or Suggested	Agency Inputs for FRM Analysis

input/Assumptions	Values	
Annual production volume	n/a	450,000
Battery chemistry	n/a	for HEV, PHEV20: LMO-G for PHEV40, EV: NMC441-G
Allowable pack voltage	for HEV: 160-260 V for PHEV, EV: 290-360 V	for HEV: ~ 120 V for PHEV, EV: ~ 360-600 V
Allowable cell capacity	< 60 A-hr	< 80 A-hr
Cells per module	16-32	32
SOC window for HEVs	25%	40%
Thermal management	Liquid	Air, for small/medium HEVs Liquid for all others

The cost projections produced by BatPaC are sensitive to the inputs and assumptions the user provides. Significant uncertainty remains regarding which will best represent manufacturer practice in the year 2020. The battery pack cost projection from BatPaC model ranges from $161/kWh for EV150 truck to $296/kWh for PHEV40 large car with NMC as chemistry and to $373/kWh for PHEV20 small car as shown in Table 3-69 to Table 3-74. The agencies note that costs used in the analysis are lower than the costs generally reported in stakeholder meetings, which ranged from $300/kW-hour to $400/kW-hour range for 2020 and $250 to $300/kW-hour range for 2025. A comparison of BatPaC modeling results to the costs used in the 2012-2016 final rule and to cost estimates compiled by EPA from battery suppliers and auto OEMs is shown in Figure 3-24.

The agencies also reviewed publically available PHEV and EV battery cost literature including reports from Anderman[67], Frost & Sullivan[68], TIAX[69], Boston Consulting Group[70], and NRC[71]. Due to the uncertainties inherent in estimating battery costs through the MY 2025 model year, a sensitivity analysis will be provided in each agency's RIA using a range of costs estimated by DOE technical experts to represent a reasonable outer bounds to the results from the BatPaC model. In a recent report to NHTSA and EPA, DOE and ANL suggested the following range for the sensitivity study with 95% confidence interval after analyzing the confidence bound using the BatPaC model. The agencies describe their respective sensitivities surrounding BatPaC costs in their respective RIAs (see Chapter 3.11 of EPA's final RIA and Chapter X of NHTSA's FRIA).

Suggested confidence bounds as percentage of the calculated point estimate for a graphite based Li-ion battery using the default inputs in BatPaC			
		Confidence Interval	
Battery type	**Cathodes**	**lower**	**upper**
HEV	**LMO, LFP, NCA, NMC**	**-10%**	**10%**
PHEV, EV	**NMC, NCA**	**-10%**	**20%**
PHEV, EV	**LMO, LFP**	**-20%**	**35%**

Figure 3-23 Table from ANL Recommendation[72]

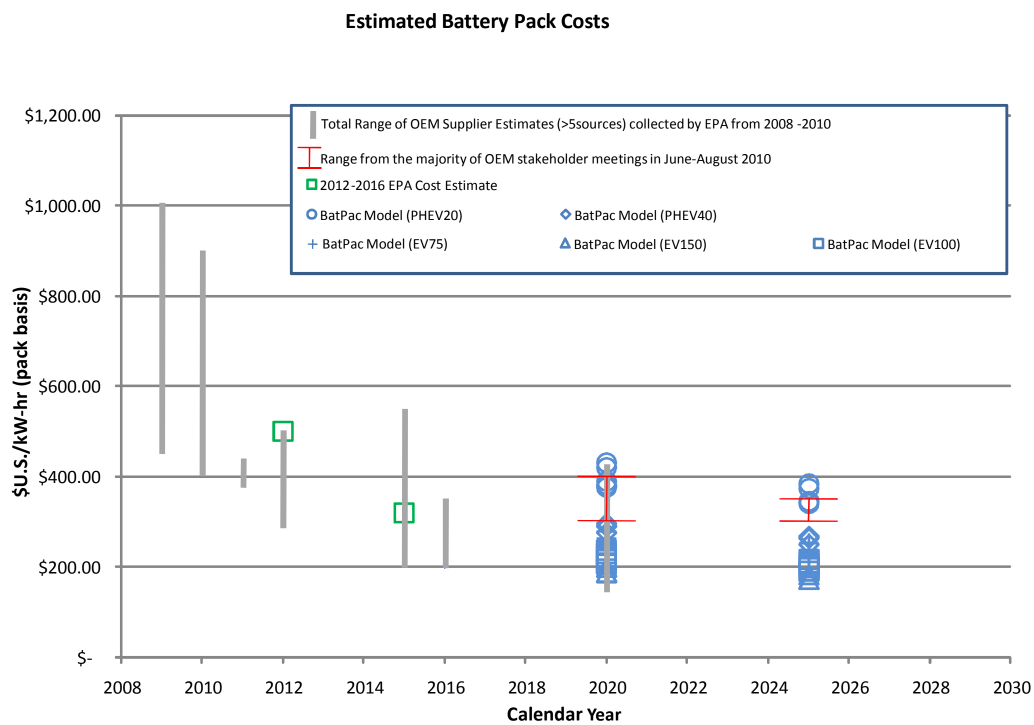


Figure 3-24 Comparison of direct manufacturing costs per unit of energy storage ($/kW-hr) between the estimates used by EPA in the 2012-2016 GHG final rule, the BatPaC model results for PHEV20, PHEV40, EV75, EV100 and EV150 packages compared to estimates from OEM battery suppliers (2009 dollars, markups not included). Multiple points shown for the BatPaC model results for PHEV 20, PHEV40, EV75, EV100 and EV150 reflect the range of energy-specific costs for EPA's subcompact through large-car package categories (see Table 3-70 through Table 3-74for details). A range of OEM estimated battery costs from stakeholder meetings is also shown for comparison (red bars) which may or may not reflect additional cost markups.

While it is expected that other Li-ion battery chemistries with higher energy density, higher power density and lower cost will likely be available in the 2017-2025 timeframe, the specific chemistries used for the cost analysis were chosen due to their known characteristics and to be consistent with both public available information on current and near term HEV, PHEV and EV product offerings from Hyundai, GM and Nissan as well as confidential business information on future products currently under development.[73,74,75,76] The cost outputs from the BatPaC model used by the agencies in this analysis are shown in Table 3-69 through Table 3-74 for different levels of applied weight reduction technology. We differentiate between "applied" weight reduction and "net" weight reduction in this analysis because to achieve the same amount of mass reduction, more mass reduction technologies might need to be applied to vehicles with electrification than with traditional powertrains because of the added weight of the electrification systems (i.e., the battery, electric motors, etc.). This also makes it clear that we have estimated vehicle level battery pack costs—and motor and other electrified vehicle specific costs—based on the net weight reduction of the vehicle. For example, a typical EV150 battery back and associated motors and other EV-specific equipment increases vehicle weight roughly 18 percent. As a result, an EV150 that applied 20 percent mass reduction technology (see section 3.4.5.5 for a full discussion of mass reduction technologies and costs) would have a net weight reduction of only 2 percent. In such a case, the agencies would estimate mass reduction costs associated with a 20 percent applied mass reduction, and EV150 costs associated with only a 2 percent net mass reduction (lower net mass reduction results in higher battery pack and motor costs). Similarly, HEV battery packs increase vehicle weight by roughly 5 or 6 percent. Therefore, for an HEV with 20 percent applied mass reduction technology—and costs associated with 20 percent applied mass reduction—would have HEV costs associated with a 15 percent net mass reduction. Furthermore, such an HEV would have an effectiveness level improvement associated with a 15 percent net mass reduction rather than a 20 percent net reduction.

Table 3-69 Direct Manufacturing Costs for P2 HEV battery packs at different levels of applied vehicle weight reduction (2010 dollars, markups not included)

P2 HEV (LMO)	0% weight reduction		2% weight reduction		7.5% weight reduction		10% weight reduction		20% weight reduction	
@ 450K/yr volume	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh
2008 Baseline										
Small Car	$726	$896	$722	$909	$712	$950	$708	$970	$700	$1,008
Standard Car	$801	$804	$796	$815	$783	$849	$777	$866	$765	$901
Large Car	$938	$809	$929	$817	$909	$848	$900	$862	$882	$894
Small MPV	$779	$747	$775	$758	$762	$790	$757	$806	$746	$839
Large MPV	$876	$682	$870	$691	$853	$718	$846	$731	$830	$760
Truck	$1,010	$676	$1,003	$685	$983	$711	$974	$724	$957	$747
2010 Baseline										
Small Car	$732	$904	$729	$918	$718	$958	$714	$978	$705	$1,017
Standard Car	$809	$813	$805	$824	$791	$858	$785	$875	$773	$909
Large Car	$950	$819	$943	$830	$920	$858	$911	$873	$893	$904
Small MPV	$788	$756	$784	$767	$771	$800	$765	$816	$754	$848
Large MPV	$878	$683	$872	$692	$855	$720	$847	$733	$832	$762
Truck	$1,019	$682	$1,012	$691	$992	$718	$983	$731	$967	$754

Table 3-70 Direct Manufacturing Costs for PHEV20 battery packs at different levels of applied vehicle weight reduction (2010 dollars, markups not included)

PHEV20 (LMO) @ 450K/yr volume	0% weight reduction		2% weight reduction		7.5% weight reduction		10% weight reduction		20% weight reduction	
	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh
2008 Baseline										
Small Car	$2,531	$364	$2,517	$364	$2,469	$370	$2,447	$371	$2,431	$373
Standard Car	$2,962	$347	$2,938	$348	$2,835	$345	$2,808	$346	$2,784	$347

Large Car	$3,734	$368	$3,696	$369	$3,592	$369	$3,546	$368	$3,510	$369
Small MPV	$2,835	$316	$2,813	$317	$2,754	$319	$2,730	$320	$2,703	$323
Large MPV	$3,424	$300	$3,393	$301	$3,309	$302	$3,274	$303	$3,244	$303
Truck	$3,874	$295	$3,834	$295	$3,732	$295	$3,681	$297	$3,671	$296
2010 Baseline										
Small Car	$2,572	$370	$2,554	$370	$2,507	$376	$2,487	$377	$2,468	$379
Standard Car	$3,019	$353	$2,992	$354	$2,927	$357	$2,858	$352	$2,829	$353
Large Car	$3,813	$376	$3,773	$376	$3,668	$376	$3,621	$376	$3,575	$376
Small MPV	$2,933	$326	$2,911	$328	$2,811	$326	$2,783	$326	$2,754	$329
Large MPV	$3,434	$301	$3,403	$302	$3,319	$303	$3,282	$303	$3,253	$304
Truck	$3,922	$298	$3,881	$298	$3,778	$299	$3,732	$301	$3,706	$298

Table 3-71 Direct Manufacturing Costs for PHEV40 battery pack at different levels of applied vehicle weight reduction (2010 dollars, markups not included)

PHEV40 (NMC)	0% weight reduction		2% weight reduction		7.5% weight reduction		10% weight reduction		20% weight reduction	
@ 450K/yr volume	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh
2008 Baseline										
Small Car	$3,644	$262	$3,619	$262	$3,542	$264	$3,542	$264	$3,542	$264
Standard Car	$4,390	$257	$4,343	$257	$4,228	$258	$4,228	$258	$4,228	$258
Large Car	$6,006	$296	$5,921	$295	$5,671	$291	$5,671	$291	$5,671	$291
Small MPV	$4,247	$236	$4,207	$237	$4,101	$238	$4,100	$237	$4,100	$237
Large MPV	$5,269	$231	$5,212	$231	$5,065	$231	$5,065	$231	$5,065	$231
Truck	$6,122	$233	$6,050	$233	$5,900	$232	$5,900	$232	$5,900	$232
2010 Baseline										
Small Car	$3,722	$268	$3,690	$267	$3,606	$269	$3,606	$269	$3,606	$269
Standard Car	$4,494	$263	$4,447	$263	$4,324	$263	$4,324	$263	$4,324	$263
Large Car	$6,158	$304	$6,073	$303	$5,850	$300	$5,850	$300	$5,850	$300
Small MPV	$4,351	$242	$4,309	$243	$4,198	$243	$4,198	$243	$4,198	$243
Large MPV	$5,286	$232	$5,228	$232	$5,080	$232	$5,080	$232	$5,080	$232
Truck	$6,215	$236	$6,142	$236	$5,980	$235	$5,980	$235	$5,980	$235

Table 3-72 Direct Manufacturing Costs for EV75 battery packs at different levels of applied vehicle weight reduction (2010 dollars, markups not included)

EV75 (NMC) @ 450K/yr volume	0% weight reduction		2% weight reduction		7.5% weight reduction		10% weight reduction		20% weight reduction	
	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh

2008 Baseline										
Small Car	$5,115	$224	$5,098	$225	$4,996	$228	$4,962	$229	$4,768	$233
Standard Car	$6,021	$215	$5,965	$215	$5,818	$216	$5,755	$216	$5,509	$219
Large Car	$7,724	$232	$7,635	$232	$7,397	$231	$7,295	$231	$6,907	$231
Small MPV	$5,995	$203	$5,952	$204	$5,843	$206	$5,800	$207	$5,625	$211
Large MPV	$7,310	$195	$7,237	$196	$7,045	$196	$6,963	$196	$6,610	$197
Truck	$8,332	$193	$8,242	$193	$8,005	$193	$7,883	$194	$7,474	$194
2010 Baseline										
Small Car	$5,232	$221	$5,195	$222	$5,106	$225	$5,071	$226	$4,912	$231
Standard Car	$6,152	$214	$6,092	$214	$5,940	$215	$5,874	$215	$5,624	$218
Large Car	$7,923	$229	$7,832	$229	$7,586	$229	$7,479	$228	$7,092	$228
Small MPV	$6,070	$203	$6,016	$203	$5,904	$205	$5,860	$206	$5,684	$210
Large MPV	$7,312	$197	$7,238	$198	$7,046	$198	$6,962	$198	$6,605	$198
Truck	$8,472	$191	$8,380	$191	$8,141	$191	$8,036	$191	$7,629	$191

Table 3-73 Direct Manufacturing Costs for EV100 battery packs at different levels of applied vehicle weight reduction (2010 dollars, markups not included)

EV100 (NMC)	0% weight reduction		2% weight reduction		7.5% weight reduction		10% weight reduction		20% weight reduction	
@ 450K/yr volume	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh
2008 Baseline										
Small Car	$6,105	$201	$6,083	$201	$5,950	$204	$5,906	$205	$5,817	$206
Standard Car	$7,054	$189	$7,001	$189	$6,826	$190	$6,770	$191	$6,662	$192
Large Car	$8,630	$195	$8,535	$195	$8,283	$194	$8,175	$194	$7,999	$194
Small MPV	$7,293	$186	$7,237	$186	$7,096	$188	$7,039	$189	$6,953	$190
Large MPV	$8,641	$173	$8,571	$174	$8,392	$175	$8,321	$176	$8,215	$177
Truck	$9,962	$173	$9,879	$174	$9,676	$175	$9,554	$176	$9,392	$177
2010 Baseline										
Small Car	$6,255	$198	$6,209	$199	$6,094	$201	$6,048	$202	$5,956	$204
Standard Car	$7,173	$187	$7,118	$188	$6,980	$190	$6,884	$189	$6,802	$190
Large Car	$8,863	$192	$8,765	$192	$8,504	$192	$8,393	$192	$8,251	$192
Small MPV	$7,375	$185	$7,318	$185	$7,174	$187	$7,117	$188	$7,031	$189
Large MPV	$8,586	$174	$8,516	$174	$8,338	$176	$8,268	$176	$8,128	$177
Truck	$10,158	$172	$10,075	$172	$9,865	$174	$9,782	$174	$9,615	$175

Table 3-74 Direct Manufacturing Costs for EV150 battery packs at different levels of applied vehicle weight reduction (2010 dollars, markups not included)

EV150 (NMC)	0% weight reduction		2% weight reduction		7.5% weight reduction		10% weight reduction		20% weight reduction	
@ 450K/yr volume	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh
2008 Baseline										
Small Car	$8,080	$177	$8,048	$178	$8,048	$178	$8,048	$178	$8,048	$178
Standard Car	$9,753	$174	$9,714	$174	$9,714	$174	$9,714	$174	$9,714	$174
Large Car	$11,120	$167	$11,073	$167	$11,073	$167	$11,073	$167	$11,073	$167
Small MPV	$10,109	$171	$10,109	$171	$10,109	$171	$10,109	$171	$10,109	$171
Large MPV	$12,114	$162	$12,112	$162	$12,112	$162	$12,112	$162	$12,112	$162
Truck	$13,878	$161	$13,818	$161	$13,759	$161	$13,759	$161	$13,759	$161
2010 Baseline										
Small Car	$8,298	$175	$8,265	$176	$8,265	$176	$8,265	$176	$8,265	$176
Standard Car	$9,928	$173	$9,888	$173	$9,888	$173	$9,888	$173	$9,888	$173
Large Car	$11,432	$166	$11,384	$166	$11,384	$166	$11,384	$166	$11,384	$166
Small MPV	$10,228	$171	$10,228	$171	$10,228	$171	$10,228	$171	$10,228	$171
Large MPV	$12,032	$162	$11,981	$163	$11,981	$163	$11,981	$163	$11,981	$163
Truck	$14,166	$160	$14,045	$160	$14,044	$160	$14,044	$160	$14,044	$160

Specifically for modeling purposes, both agencies wanted HEV/PHEV/EV battery pack costs based on net weight reduction rather than applied weight reduction as shown in Table 3-69 through Table 3-74 above. The agencies did this by first determining the average weight differences (applied weight reduction vs net weight reduction) for each of the 6 major vehicle classes (small car, standard car, large car, small MPV, large MPV & truck) and each of the electrification types (P2 HEV, PHEV & EV). Due to the weight increases of adding the electrification system and battery pack and the weight decreases by applying smaller or no conventional internal combustion engine, the net mass reduction for HEV, PHEV and EV varies for different electrification packages and vehicle classes. For example, for a 20-mile small car PHEV, a 5% mass reduction of the glider is offset by the additional weight of the electrification system. Said another way, a 5% mass reduction needs to be applied to the glider to achieve a net 0% overall vehicle mass reduction for a PHEV20 small car. Those weight reduction differences are shown in Table 3-75.

Table 3-75 EPA and NHTSA Weight Reduction Offset Associated with Electrification Technologies

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
2008 Baseline						
Small car	5%	7%	13%	0%	6%	18%
Standard car	5%	7%	12%	0%	6%	18%
Large car	5%	8%	14%	-1%	5%	17%
Small MPV	5%	7%	12%	1%	7%	19%
Large MPV	5%	7%	12%	0%	6%	18%

Truck	4%	7%	12%	1%	7%	19%
2010 Baseline						
Small car	5%	7%	12%	0%	6%	19%
Standard car	5%	7%	12%	1%	7%	19%
Large car	5%	8%	13%	0%	6%	17%
Small MPV	5%	7%	12%	1%	7%	19%
Large MPV	5%	7%	12%	1%	7%	19%
Truck	4%	7%	12%	0%	6%	19%
Notes: For example, PHEV40-specific technologies add 12-14% to vehicle weight so that a 20% applied weight reduction would result in a 6-8% net weight reduction. While an EV75 can actually reduce vehicle weight by 1-2% (i.e., battery packs and motors weigh less than the removed internal combustion engine and transmission), the agencies used a value of 0% where negative entries are shown.						

The agencies then generated linear regressions of battery pack costs against percentage net weight reduction using the costs shown in Table 3-69 through Table 3-74 and the weight reduction offsets shown in Table 3-75. These results are shown in Table 3-76.

Table 3-76 EPA and NHTSA Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Weight Reduction (2010$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
2008 Baseline						
Small car	-$181x+$726	-$861x+$2,533	-$1,517x+$3,646	-$1,859x+$5,131	-$2,168x+$6,115	-$2,045x+$8,080
Standard car	-$240x+$801	-$1,543x+$2,962	-$2,195x+$4,389	-$2,754x+$6,023	-$2,958x+$7,056	-$2,552x+$9,753
Large car	-$369x+$937	-$1,881x+$3,734	-$4,700x+$6,010	-$4,356x+$7,725	-$4,647x+$8,630	-$2,840x+$11,120
Small MPV	-$224x+$779	-$1,073x+$2,835	-$1,957x+$4,247	-$2,061x+$5,997	-$2,649x+$7,293	-$19x+$10,109
Large MPV	-$303x+$876					
Truck	-$367x+$1,010					
2010 Baseline						
Small car	-$188x+$733	-$866x+$2,572	-$1,612x+$3,722	-$1,717x+$5,233	-$2,209x+$6,256	-$2,700x+$8,298
Standard car	-$248x+$810	-$1,573x+$3,024	-$2,291x+$4,494	-$2,887x+$6,154	-$2,883x+$7,178	-$3,242x+$9,928
Large car	-$387x+$950	-$1,957x+$3,813	-$4,217x+$6,158	-$4,543x+$7,925	-$4,744x+$8,862	-$4,250x+$11,432
Small MPV	-$233x+$789	-$1,516x+$2,934	-$2,022x+$4,350	-$2,155x+$6,067	-$2,706x+$7,375	-$21x+$10,228
Large MPV	-$305x+$878					
Truck	-$364x+$1,019					

Notes:
"x" in the equations represents the net weight reduction as a percentage, so a small car P2 HEV battery pack (2008 baseline) with a 20% applied weight reduction and, therefore, a 15% net weight reduction would cost (-$181)x(15%)+$726=$698.
The agencies did not regress PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

For P2 HEV battery packs, the direct manufacturing costs shown in Table 3-76 are considered applicable to the 2017MY. The agencies consider the P2 battery packs technology to be on the flat portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a high1 complexity ICM of 1.56 through 2024 then 1.35 thereafter. For PHEV and EV battery packs, the direct manufacturing costs shown in Table 3-76 are considered applicable to the 2025MY. For the PHEV and EV battery packs, the agencies have applied the learning curve discussed in Section 3.2.3. The agencies have applied a high2 complexity ICM of 1.77 through 2024 then 1.50 thereafter. The resultant costs for P2 HEV, PHEV20, PHEV40, EV75, EV100 and EV150 battery packs for the 2008 and 2010 baselines are shown in Table 3-77 through Table 3-87, respectively.

Table 3-77 Costs for P2 HEV Battery Packs for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	5%	$717	$695	$674	$654	$634	$615	$597	$579	$562
DMC	Small car	15%	10%	$707	$686	$666	$646	$626	$608	$589	$572	$554
DMC	Small car	20%	15%	$698	$677	$657	$637	$618	$600	$582	$564	$547
DMC	Standard car	10%	5%	$789	$765	$742	$720	$698	$677	$657	$637	$618
DMC	Standard car	15%	10%	$777	$753	$731	$709	$688	$667	$647	$628	$609
DMC	Standard car	20%	15%	$765	$742	$719	$698	$677	$657	$637	$618	$599
DMC	Large car	10%	5%	$919	$891	$864	$838	$813	$789	$765	$742	$720
DMC	Large car	15%	10%	$900	$873	$847	$821	$797	$773	$750	$727	$705
DMC	Large car	20%	15%	$882	$855	$830	$805	$781	$757	$734	$712	$691
DMC	Small MPV	10%	5%	$768	$745	$722	$701	$680	$659	$640	$620	$602
DMC	Small MPV	15%	10%	$757	$734	$712	$690	$670	$650	$630	$611	$593
DMC	Small MPV	20%	15%	$745	$723	$701	$680	$660	$640	$621	$602	$584
DMC	Large MPV	10%	5%	$861	$835	$810	$786	$762	$739	$717	$695	$675
DMC	Large MPV	15%	10%	$846	$820	$796	$772	$749	$726	$704	$683	$663
DMC	Large MPV	20%	15%	$830	$805	$781	$758	$735	$713	$692	$671	$651
DMC	Truck	10%	6%	$988	$958	$930	$902	$875	$848	$823	$798	$774
DMC	Truck	15%	11%	$970	$941	$912	$885	$858	$833	$808	$783	$760
DMC	Truck	20%	16%	$951	$923	$895	$868	$842	$817	$792	$769	$746
IC	Small car	10%	5%	$404	$402	$401	$400	$399	$397	$396	$395	$243
IC	Small car	15%	10%	$399	$397	$396	$395	$393	$392	$391	$390	$239
IC	Small car	20%	15%	$394	$392	$391	$390	$388	$387	$386	$385	$236
IC	Standard car	10%	5%	$444	$443	$441	$440	$439	$437	$436	$435	$267
IC	Standard car	15%	10%	$438	$436	$435	$433	$432	$431	$429	$428	$263
IC	Standard car	20%	15%	$431	$429	$428	$427	$425	$424	$423	$421	$259
IC	Large car	10%	5%	$518	$516	$514	$512	$511	$509	$508	$506	$311
IC	Large car	15%	10%	$507	$506	$504	$502	$501	$499	$498	$496	$305
IC	Large car	20%	15%	$497	$495	$494	$492	$490	$489	$487	$486	$298
IC	Small MPV	10%	5%	$433	$431	$430	$428	$427	$426	$424	$423	$260
IC	Small MPV	15%	10%	$426	$425	$424	$422	$421	$419	$418	$417	$256
IC	Small MPV	20%	15%	$420	$419	$417	$416	$415	$413	$412	$411	$252
IC	Large MPV	10%	5%	$485	$483	$482	$480	$479	$477	$476	$474	$291
IC	Large MPV	15%	10%	$477	$475	$473	$472	$470	$469	$467	$466	$286
IC	Large MPV	20%	15%	$468	$466	$465	$463	$462	$460	$459	$458	$281
IC	Truck	10%	6%	$557	$555	$553	$551	$549	$548	$546	$545	$334
IC	Truck	15%	11%	$546	$545	$543	$541	$539	$538	$536	$534	$328
IC	Truck	20%	16%	$536	$534	$533	$531	$529	$527	$526	$524	$322
TC	Small car	10%	5%	$1,120	$1,097	$1,075	$1,054	$1,033	$1,013	$993	$974	$804
TC	Small car	15%	10%	$1,106	$1,084	$1,062	$1,040	$1,020	$1,000	$980	$962	$794
TC	Small car	20%	15%	$1,092	$1,070	$1,048	$1,027	$1,007	$987	$968	$949	$784
TC	Standard car	10%	5%	$1,233	$1,208	$1,183	$1,160	$1,137	$1,114	$1,093	$1,072	$885
TC	Standard car	15%	10%	$1,214	$1,190	$1,165	$1,142	$1,119	$1,098	$1,076	$1,056	$872
TC	Standard car	20%	15%	$1,196	$1,171	$1,147	$1,125	$1,102	$1,081	$1,060	$1,039	$858
TC	Large car	10%	5%	$1,436	$1,407	$1,378	$1,351	$1,324	$1,298	$1,273	$1,248	$1,031
TC	Large car	15%	10%	$1,407	$1,379	$1,351	$1,324	$1,297	$1,272	$1,247	$1,223	$1,010
TC	Large car	20%	15%	$1,379	$1,350	$1,323	$1,297	$1,271	$1,246	$1,222	$1,198	$989
TC	Small MPV	10%	5%	$1,201	$1,176	$1,152	$1,129	$1,107	$1,085	$1,064	$1,044	$862
TC	Small MPV	15%	10%	$1,183	$1,159	$1,135	$1,113	$1,091	$1,069	$1,048	$1,028	$849

TC	Small MPV	20%	15%	$1,165	$1,142	$1,119	$1,096	$1,074	$1,053	$1,033	$1,013	$836
TC	Large MPV	10%	5%	$1,346	$1,318	$1,292	$1,266	$1,241	$1,216	$1,193	$1,170	$966
TC	Large MPV	15%	10%	$1,322	$1,295	$1,269	$1,243	$1,219	$1,195	$1,172	$1,149	$949
TC	Large MPV	20%	15%	$1,298	$1,272	$1,246	$1,221	$1,197	$1,174	$1,151	$1,129	$932
TC	Truck	10%	6%	$1,545	$1,513	$1,483	$1,453	$1,424	$1,396	$1,369	$1,343	$1,109
TC	Truck	15%	11%	$1,516	$1,485	$1,455	$1,426	$1,398	$1,370	$1,344	$1,318	$1,088
TC	Truck	20%	16%	$1,487	$1,457	$1,428	$1,399	$1,371	$1,344	$1,318	$1,293	$1,068

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-78 Costs for P2 HEV Battery Packs for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	5%	$723	$701	$680	$660	$640	$621	$602	$584	$567
DMC	Small car	15%	10%	$714	$692	$672	$651	$632	$613	$595	$577	$559
DMC	Small car	20%	15%	$704	$683	$663	$643	$624	$605	$587	$569	$552
DMC	Standard car	10%	5%	$797	$773	$750	$727	$706	$685	$664	$644	$625
DMC	Standard car	15%	10%	$785	$761	$738	$716	$695	$674	$654	$634	$615
DMC	Standard car	20%	15%	$772	$749	$727	$705	$684	$663	$643	$624	$605
DMC	Large car	10%	5%	$931	$903	$876	$849	$824	$799	$775	$752	$729
DMC	Large car	15%	10%	$911	$884	$857	$832	$807	$782	$759	$736	$714
DMC	Large car	20%	15%	$892	$865	$839	$814	$790	$766	$743	$721	$699
DMC	Small MPV	10%	5%	$777	$754	$731	$709	$688	$667	$647	$628	$609
DMC	Small MPV	15%	10%	$765	$742	$720	$698	$677	$657	$637	$618	$600
DMC	Small MPV	20%	15%	$754	$731	$709	$688	$667	$647	$628	$609	$591
DMC	Large MPV	10%	5%	$863	$837	$812	$787	$764	$741	$719	$697	$676
DMC	Large MPV	15%	10%	$847	$822	$797	$773	$750	$728	$706	$685	$664
DMC	Large MPV	20%	15%	$832	$807	$783	$759	$737	$715	$693	$672	$652
DMC	Truck	10%	6%	$997	$967	$938	$910	$883	$856	$831	$806	$781
DMC	Truck	15%	11%	$979	$949	$921	$893	$867	$841	$815	$791	$767
DMC	Truck	20%	16%	$961	$932	$904	$877	$850	$825	$800	$776	$753
IC	Small car	10%	5%	$408	$406	$405	$403	$402	$401	$400	$399	$245
IC	Small car	15%	10%	$402	$401	$400	$398	$397	$396	$395	$393	$242
IC	Small car	20%	15%	$397	$396	$394	$393	$392	$391	$389	$388	$238
IC	Standard car	10%	5%	$449	$448	$446	$445	$443	$442	$441	$439	$270
IC	Standard car	15%	10%	$442	$441	$439	$438	$436	$435	$434	$433	$266
IC	Standard car	20%	15%	$435	$434	$432	$431	$430	$428	$427	$426	$261
IC	Large car	10%	5%	$524	$523	$521	$519	$518	$516	$514	$513	$315
IC	Large car	15%	10%	$514	$512	$510	$508	$507	$505	$504	$502	$308
IC	Large car	20%	15%	$503	$501	$499	$498	$496	$494	$493	$492	$302
IC	Small MPV	10%	5%	$438	$436	$435	$433	$432	$431	$429	$428	$263
IC	Small MPV	15%	10%	$431	$430	$428	$427	$426	$424	$423	$422	$259
IC	Small MPV	20%	15%	$425	$423	$422	$420	$419	$418	$417	$415	$255
IC	Large MPV	10%	5%	$486	$485	$483	$481	$480	$478	$477	$475	$292
IC	Large MPV	15%	10%	$478	$476	$474	$473	$471	$470	$468	$467	$287
IC	Large MPV	20%	15%	$469	$467	$466	$464	$463	$461	$460	$459	$282
IC	Truck	10%	6%	$562	$560	$558	$556	$555	$553	$551	$550	$338
IC	Truck	15%	11%	$552	$550	$548	$546	$544	$543	$541	$540	$331
IC	Truck	20%	16%	$541	$540	$538	$536	$534	$533	$531	$529	$325
TC	Small car	10%	5%	$1,131	$1,108	$1,085	$1,063	$1,042	$1,022	$1,002	$983	$812
TC	Small car	15%	10%	$1,116	$1,093	$1,071	$1,050	$1,029	$1,009	$989	$970	$801
TC	Small car	20%	15%	$1,101	$1,079	$1,057	$1,036	$1,015	$995	$976	$957	$790
TC	Standard car	10%	5%	$1,246	$1,221	$1,196	$1,172	$1,149	$1,126	$1,105	$1,083	$895
TC	Standard car	15%	10%	$1,227	$1,202	$1,178	$1,154	$1,131	$1,109	$1,087	$1,067	$881
TC	Standard car	20%	15%	$1,208	$1,183	$1,159	$1,136	$1,113	$1,091	$1,070	$1,050	$867
TC	Large car	10%	5%	$1,455	$1,425	$1,396	$1,369	$1,341	$1,315	$1,290	$1,265	$1,044
TC	Large car	15%	10%	$1,425	$1,396	$1,367	$1,340	$1,313	$1,288	$1,263	$1,238	$1,023
TC	Large car	20%	15%	$1,394	$1,366	$1,338	$1,312	$1,286	$1,260	$1,236	$1,212	$1,001
TC	Small MPV	10%	5%	$1,215	$1,190	$1,166	$1,142	$1,120	$1,098	$1,077	$1,056	$872

TC	Small MPV	15%	10%	$1,196	$1,172	$1,148	$1,125	$1,103	$1,081	$1,060	$1,040	$859
TC	Small MPV	20%	15%	$1,178	$1,154	$1,131	$1,108	$1,086	$1,065	$1,044	$1,024	$846
TC	Large MPV	10%	5%	$1,349	$1,321	$1,295	$1,269	$1,243	$1,219	$1,195	$1,172	$968
TC	Large MPV	15%	10%	$1,325	$1,298	$1,272	$1,246	$1,222	$1,198	$1,174	$1,152	$951
TC	Large MPV	20%	15%	$1,301	$1,275	$1,249	$1,224	$1,200	$1,176	$1,153	$1,131	$934
TC	Truck	10%	6%	$1,559	$1,527	$1,496	$1,466	$1,437	$1,409	$1,382	$1,355	$1,119
TC	Truck	15%	11%	$1,531	$1,499	$1,469	$1,440	$1,411	$1,383	$1,356	$1,330	$1,099
TC	Truck	20%	16%	$1,502	$1,471	$1,442	$1,413	$1,385	$1,358	$1,331	$1,306	$1,078

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-79 Costs for PHEV20 Battery Packs for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	3%	$4,896	$3,917	$3,917	$3,134	$3,134	$3,134	$3,134	$3,134	$2,507
DMC	Small car	15%	8%	$4,812	$3,850	$3,850	$3,080	$3,080	$3,080	$3,080	$3,080	$2,464
DMC	Small car	20%	13%	$4,728	$3,783	$3,783	$3,026	$3,026	$3,026	$3,026	$3,026	$2,421
DMC	Standard car	10%	3%	$5,696	$4,557	$4,557	$3,645	$3,645	$3,645	$3,645	$3,645	$2,916
DMC	Standard car	15%	8%	$5,545	$4,436	$4,436	$3,549	$3,549	$3,549	$3,549	$3,549	$2,839
DMC	Standard car	20%	13%	$5,394	$4,315	$4,315	$3,452	$3,452	$3,452	$3,452	$3,452	$2,762
DMC	Large car	10%	2%	$7,219	$5,775	$5,775	$4,620	$4,620	$4,620	$4,620	$4,620	$3,696
DMC	Large car	15%	7%	$7,035	$5,628	$5,628	$4,502	$4,502	$4,502	$4,502	$4,502	$3,602
DMC	Large car	20%	12%	$6,851	$5,481	$5,481	$4,385	$4,385	$4,385	$4,385	$4,385	$3,508
DMC	Small MPV	10%	3%	$5,474	$4,379	$4,379	$3,504	$3,504	$3,504	$3,504	$3,504	$2,803
DMC	Small MPV	15%	8%	$5,370	$4,296	$4,296	$3,436	$3,436	$3,436	$3,436	$3,436	$2,749
DMC	Small MPV	20%	13%	$5,265	$4,212	$4,212	$3,369	$3,369	$3,369	$3,369	$3,369	$2,696
IC	Small car	10%	3%	$2,106	$2,034	$2,034	$1,977	$1,977	$1,977	$1,977	$1,977	$1,245
IC	Small car	15%	8%	$2,070	$1,999	$1,999	$1,943	$1,943	$1,943	$1,943	$1,943	$1,224
IC	Small car	20%	13%	$2,034	$1,964	$1,964	$1,909	$1,909	$1,909	$1,909	$1,909	$1,202
IC	Standard car	10%	3%	$2,450	$2,366	$2,366	$2,299	$2,299	$2,299	$2,299	$2,299	$1,448
IC	Standard car	15%	8%	$2,385	$2,304	$2,304	$2,238	$2,238	$2,238	$2,238	$2,238	$1,410
IC	Standard car	20%	13%	$2,321	$2,241	$2,241	$2,178	$2,178	$2,178	$2,178	$2,178	$1,372
IC	Large car	10%	2%	$3,105	$2,999	$2,999	$2,914	$2,914	$2,914	$2,914	$2,914	$1,835
IC	Large car	15%	7%	$3,026	$2,923	$2,923	$2,840	$2,840	$2,840	$2,840	$2,840	$1,789
IC	Large car	20%	12%	$2,947	$2,846	$2,846	$2,766	$2,766	$2,766	$2,766	$2,766	$1,742
IC	Small MPV	10%	3%	$2,355	$2,274	$2,274	$2,210	$2,210	$2,210	$2,210	$2,210	$1,392
IC	Small MPV	15%	8%	$2,310	$2,231	$2,231	$2,168	$2,168	$2,168	$2,168	$2,168	$1,365
IC	Small MPV	20%	13%	$2,265	$2,187	$2,187	$2,125	$2,125	$2,125	$2,125	$2,125	$1,339
TC	Small car	10%	3%	$7,003	$5,951	$5,951	$5,110	$5,110	$5,110	$5,110	$5,110	$3,752
TC	Small car	15%	8%	$6,883	$5,849	$5,849	$5,023	$5,023	$5,023	$5,023	$5,023	$3,688
TC	Small car	20%	13%	$6,762	$5,747	$5,747	$4,935	$4,935	$4,935	$4,935	$4,935	$3,623
TC	Standard car	10%	3%	$8,146	$6,923	$6,923	$5,944	$5,944	$5,944	$5,944	$5,944	$4,364
TC	Standard car	15%	8%	$7,930	$6,740	$6,740	$5,787	$5,787	$5,787	$5,787	$5,787	$4,249
TC	Standard car	20%	13%	$7,715	$6,556	$6,556	$5,630	$5,630	$5,630	$5,630	$5,630	$4,133
TC	Large car	10%	2%	$10,324	$8,774	$8,774	$7,534	$7,534	$7,534	$7,534	$7,534	$5,531
TC	Large car	15%	7%	$10,061	$8,551	$8,551	$7,342	$7,342	$7,342	$7,342	$7,342	$5,391
TC	Large car	20%	12%	$9,799	$8,327	$8,327	$7,151	$7,151	$7,151	$7,151	$7,151	$5,250
TC	Small MPV	10%	3%	$7,829	$6,654	$6,654	$5,713	$5,713	$5,713	$5,713	$5,713	$4,195

TC	Small MPV	15%	8%	$7,679	$6,526	$6,526	$5,604	$5,604	$5,604	$5,604	$5,604	$4,114
TC	Small MPV	20%	13%	$7,530	$6,399	$6,399	$5,495	$5,495	$5,495	$5,495	$5,495	$4,034

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-80 Costs for PHEV20 Battery Packs for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	3%	$4,973	$3,978	$3,978	$3,182	$3,182	$3,182	$3,182	$3,182	$2,546
DMC	Small car	15%	8%	$4,888	$3,910	$3,910	$3,128	$3,128	$3,128	$3,128	$3,128	$2,503
DMC	Small car	20%	13%	$4,804	$3,843	$3,843	$3,074	$3,074	$3,074	$3,074	$3,074	$2,459
DMC	Standard car	10%	3%	$5,815	$4,652	$4,652	$3,722	$3,722	$3,722	$3,722	$3,722	$2,977
DMC	Standard car	15%	8%	$5,661	$4,529	$4,529	$3,623	$3,623	$3,623	$3,623	$3,623	$2,899
DMC	Standard car	20%	13%	$5,508	$4,406	$4,406	$3,525	$3,525	$3,525	$3,525	$3,525	$2,820
DMC	Large car	10%	2%	$7,371	$5,897	$5,897	$4,718	$4,718	$4,718	$4,718	$4,718	$3,774
DMC	Large car	15%	7%	$7,180	$5,744	$5,744	$4,595	$4,595	$4,595	$4,595	$4,595	$3,676
DMC	Large car	20%	12%	$6,989	$5,591	$5,591	$4,473	$4,473	$4,473	$4,473	$4,473	$3,578
DMC	Small MPV	10%	3%	$5,643	$4,514	$4,514	$3,611	$3,611	$3,611	$3,611	$3,611	$2,889
DMC	Small MPV	15%	8%	$5,494	$4,396	$4,396	$3,516	$3,516	$3,516	$3,516	$3,516	$2,813
DMC	Small MPV	20%	13%	$5,346	$4,277	$4,277	$3,422	$3,422	$3,422	$3,422	$3,422	$2,737
IC	Small car	10%	3%	$2,139	$2,066	$2,066	$2,007	$2,007	$2,007	$2,007	$2,007	$1,264
IC	Small car	15%	8%	$2,103	$2,031	$2,031	$1,973	$1,973	$1,973	$1,973	$1,973	$1,243
IC	Small car	20%	13%	$2,066	$1,996	$1,996	$1,939	$1,939	$1,939	$1,939	$1,939	$1,221
IC	Standard car	10%	3%	$2,501	$2,416	$2,416	$2,347	$2,347	$2,347	$2,347	$2,347	$1,479
IC	Standard car	15%	8%	$2,435	$2,352	$2,352	$2,285	$2,285	$2,285	$2,285	$2,285	$1,439
IC	Standard car	20%	13%	$2,369	$2,288	$2,288	$2,223	$2,223	$2,223	$2,223	$2,223	$1,400
IC	Large car	10%	2%	$3,171	$3,063	$3,063	$2,976	$2,976	$2,976	$2,976	$2,976	$1,874
IC	Large car	15%	7%	$3,089	$2,983	$2,983	$2,899	$2,899	$2,899	$2,899	$2,899	$1,826
IC	Large car	20%	12%	$3,007	$2,904	$2,904	$2,821	$2,821	$2,821	$2,821	$2,821	$1,777
IC	Small MPV	10%	3%	$2,427	$2,344	$2,344	$2,278	$2,278	$2,278	$2,278	$2,278	$1,435
IC	Small MPV	15%	8%	$2,364	$2,283	$2,283	$2,218	$2,218	$2,218	$2,218	$2,218	$1,397
IC	Small MPV	20%	13%	$2,300	$2,221	$2,221	$2,158	$2,158	$2,158	$2,158	$2,158	$1,359
TC	Small car	10%	3%	$7,112	$6,044	$6,044	$5,190	$5,190	$5,190	$5,190	$5,190	$3,810
TC	Small car	15%	8%	$6,991	$5,941	$5,941	$5,102	$5,102	$5,102	$5,102	$5,102	$3,746
TC	Small car	20%	13%	$6,870	$5,838	$5,838	$5,013	$5,013	$5,013	$5,013	$5,013	$3,681
TC	Standard car	10%	3%	$8,316	$7,068	$7,068	$6,069	$6,069	$6,069	$6,069	$6,069	$4,456
TC	Standard car	15%	8%	$8,097	$6,881	$6,881	$5,908	$5,908	$5,908	$5,908	$5,908	$4,338
TC	Standard car	20%	13%	$7,877	$6,694	$6,694	$5,748	$5,748	$5,748	$5,748	$5,748	$4,220
TC	Large car	10%	2%	$10,542	$8,960	$8,960	$7,693	$7,693	$7,693	$7,693	$7,693	$5,648
TC	Large car	15%	7%	$10,269	$8,727	$8,727	$7,494	$7,494	$7,494	$7,494	$7,494	$5,502
TC	Large car	20%	12%	$9,996	$8,495	$8,495	$7,294	$7,294	$7,294	$7,294	$7,294	$5,356
TC	Small MPV	10%	3%	$8,070	$6,858	$6,858	$5,889	$5,889	$5,889	$5,889	$5,889	$4,324
TC	Small MPV	15%	8%	$7,858	$6,678	$6,678	$5,734	$5,734	$5,734	$5,734	$5,734	$4,210
TC	Small MPV	20%	13%	$7,646	$6,498	$6,498	$5,580	$5,580	$5,580	$5,580	$5,580	$4,097

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-81 Costs for PHEV40 Battery Packs for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	15%	2%	$7,063	$5,650	$5,650	$4,520	$4,520	$4,520	$4,520	$4,520	$3,616
DMC	Small car	20%	7%	$6,915	$5,532	$5,532	$4,425	$4,425	$4,425	$4,425	$4,425	$3,540
DMC	Standard car	15%	3%	$8,443	$6,754	$6,754	$5,404	$5,404	$5,404	$5,404	$5,404	$4,323
DMC	Standard car	20%	8%	$8,229	$6,583	$6,583	$5,266	$5,266	$5,266	$5,266	$5,266	$4,213
DMC	Large car	15%	1%	$11,646	$9,317	$9,317	$7,453	$7,453	$7,453	$7,453	$7,453	$5,963
DMC	Large car	20%	6%	$11,187	$8,950	$8,950	$7,160	$7,160	$7,160	$7,160	$7,160	$5,728
DMC	Small MPV	15%	3%	$8,179	$6,544	$6,544	$5,235	$5,235	$5,235	$5,235	$5,235	$4,188
DMC	Small MPV	20%	8%	$7,988	$6,391	$6,391	$5,113	$5,113	$5,113	$5,113	$5,113	$4,090
IC	Small car	15%	2%	$3,038	$2,934	$2,934	$2,851	$2,851	$2,851	$2,851	$2,851	$1,796
IC	Small car	20%	7%	$2,975	$2,873	$2,873	$2,791	$2,791	$2,791	$2,791	$2,791	$1,758
IC	Standard car	15%	3%	$3,632	$3,508	$3,508	$3,408	$3,408	$3,408	$3,408	$3,408	$2,147
IC	Standard car	20%	8%	$3,540	$3,419	$3,419	$3,322	$3,322	$3,322	$3,322	$3,322	$2,092
IC	Large car	15%	1%	$5,010	$4,838	$4,838	$4,701	$4,701	$4,701	$4,701	$4,701	$2,961
IC	Large car	20%	6%	$4,813	$4,648	$4,648	$4,516	$4,516	$4,516	$4,516	$4,516	$2,844
IC	Small MPV	15%	3%	$3,519	$3,398	$3,398	$3,302	$3,302	$3,302	$3,302	$3,302	$2,080
IC	Small MPV	20%	8%	$3,436	$3,319	$3,319	$3,225	$3,225	$3,225	$3,225	$3,225	$2,031
TC	Small car	15%	2%	$10,101	$8,584	$8,584	$7,371	$7,371	$7,371	$7,371	$7,371	$5,412
TC	Small car	20%	7%	$9,889	$8,404	$8,404	$7,217	$7,217	$7,217	$7,217	$7,217	$5,298
TC	Standard car	15%	3%	$12,075	$10,262	$10,262	$8,812	$8,812	$8,812	$8,812	$8,812	$6,470
TC	Standard car	20%	8%	$11,769	$10,002	$10,002	$8,588	$8,588	$8,588	$8,588	$8,588	$6,305
TC	Large car	15%	1%	$16,656	$14,155	$14,155	$12,155	$12,155	$12,155	$12,155	$12,155	$8,924
TC	Large car	20%	6%	$16,000	$13,597	$13,597	$11,676	$11,676	$11,676	$11,676	$11,676	$8,572
TC	Small MPV	15%	3%	$11,698	$9,942	$9,942	$8,537	$8,537	$8,537	$8,537	$8,537	$6,268
TC	Small MPV	20%	8%	$11,425	$9,709	$9,709	$8,337	$8,337	$8,337	$8,337	$8,337	$6,121

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-82 Costs for PHEV40 Battery Packs for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	15%	3%	$7,175	$5,740	$5,740	$4,592	$4,592	$4,592	$4,592	$4,592	$3,674
DMC	Small car	20%	8%	$7,018	$5,614	$5,614	$4,491	$4,491	$4,491	$4,491	$4,491	$3,593
DMC	Standard car	15%	3%	$8,642	$6,914	$6,914	$5,531	$5,531	$5,531	$5,531	$5,531	$4,425
DMC	Standard car	20%	8%	$8,418	$6,735	$6,735	$5,388	$5,388	$5,388	$5,388	$5,388	$4,310
DMC	Large car	15%	2%	$11,862	$9,490	$9,490	$7,592	$7,592	$7,592	$7,592	$7,592	$6,073

DMC	Large car	20%	7%	$11,450	$9,160	$9,160	$7,328	$7,328	$7,328	$7,328	$7,328	$5,863
DMC	Small MPV	15%	3%	$8,378	$6,702	$6,702	$5,362	$5,362	$5,362	$5,362	$5,362	$4,290
DMC	Small MPV	20%	8%	$8,180	$6,544	$6,544	$5,235	$5,235	$5,235	$5,235	$5,235	$4,188
IC	Small car	15%	3%	$3,087	$2,981	$2,981	$2,896	$2,896	$2,896	$2,896	$2,896	$1,824
IC	Small car	20%	8%	$3,019	$2,916	$2,916	$2,833	$2,833	$2,833	$2,833	$2,833	$1,784
IC	Standard car	15%	3%	$3,718	$3,591	$3,591	$3,489	$3,489	$3,489	$3,489	$3,489	$2,197
IC	Standard car	20%	8%	$3,622	$3,498	$3,498	$3,398	$3,398	$3,398	$3,398	$3,398	$2,141
IC	Large car	15%	2%	$5,103	$4,928	$4,928	$4,789	$4,789	$4,789	$4,789	$4,789	$3,016
IC	Large car	20%	7%	$4,926	$4,757	$4,757	$4,622	$4,622	$4,622	$4,622	$4,622	$2,911
IC	Small MPV	15%	3%	$3,604	$3,481	$3,481	$3,382	$3,382	$3,382	$3,382	$3,382	$2,130
IC	Small MPV	20%	8%	$3,519	$3,399	$3,399	$3,302	$3,302	$3,302	$3,302	$3,302	$2,080
TC	Small car	15%	3%	$10,262	$8,721	$8,721	$7,488	$7,488	$7,488	$7,488	$7,488	$5,498
TC	Small car	20%	8%	$10,037	$8,530	$8,530	$7,324	$7,324	$7,324	$7,324	$7,324	$5,377
TC	Standard car	15%	3%	$12,360	$10,504	$10,504	$9,020	$9,020	$9,020	$9,020	$9,020	$6,622
TC	Standard car	20%	8%	$12,040	$10,232	$10,232	$8,786	$8,786	$8,786	$8,786	$8,786	$6,451
TC	Large car	15%	2%	$16,965	$14,418	$14,418	$12,380	$12,380	$12,380	$12,380	$12,380	$9,090
TC	Large car	20%	7%	$16,376	$13,918	$13,918	$11,951	$11,951	$11,951	$11,951	$11,951	$8,774
TC	Small MPV	15%	3%	$11,982	$10,183	$10,183	$8,744	$8,744	$8,744	$8,744	$8,744	$6,420
TC	Small MPV	20%	8%	$11,700	$9,943	$9,943	$8,538	$8,538	$8,538	$8,538	$8,538	$6,268

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-83 Costs for EV75 Battery Packs for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	10%	$9,658	$7,726	$7,726	$6,181	$6,181	$6,181	$6,181	$6,181	$4,945
DMC	Small car	15%	15%	$9,476	$7,581	$7,581	$6,065	$6,065	$6,065	$6,065	$6,065	$4,852
DMC	Small car	20%	20%	$9,294	$7,436	$7,436	$5,948	$5,948	$5,948	$5,948	$5,948	$4,759
DMC	Standard car	10%	10%	$11,226	$8,980	$8,980	$7,184	$7,184	$7,184	$7,184	$7,184	$5,747
DMC	Standard car	15%	15%	$10,957	$8,765	$8,765	$7,012	$7,012	$7,012	$7,012	$7,012	$5,610
DMC	Standard car	20%	20%	$10,688	$8,550	$8,550	$6,840	$6,840	$6,840	$6,840	$6,840	$5,472
DMC	Large car	10%	10%	$14,236	$11,389	$11,389	$9,111	$9,111	$9,111	$9,111	$9,111	$7,289
DMC	Large car	15%	15%	$13,811	$11,049	$11,049	$8,839	$8,839	$8,839	$8,839	$8,839	$7,071
DMC	Large car	20%	20%	$13,385	$10,708	$10,708	$8,567	$8,567	$8,567	$8,567	$8,567	$6,853
DMC	Small MPV	10%	9%	$11,350	$9,080	$9,080	$7,264	$7,264	$7,264	$7,264	$7,264	$5,811
DMC	Small MPV	15%	14%	$11,149	$8,919	$8,919	$7,135	$7,135	$7,135	$7,135	$7,135	$5,708
DMC	Small MPV	20%	19%	$10,947	$8,758	$8,758	$7,006	$7,006	$7,006	$7,006	$7,006	$5,605
IC	Small car	10%	10%	$4,155	$4,012	$4,012	$3,899	$3,899	$3,899	$3,899	$3,899	$2,456
IC	Small car	15%	15%	$4,076	$3,937	$3,937	$3,825	$3,825	$3,825	$3,825	$3,825	$2,409

IC	Small car	20%	20%	$3,998	$3,861	$3,861	$3,752	$3,752	$3,752	$3,752	$3,752	$2,363
IC	Standard car	10%	10%	$4,829	$4,664	$4,664	$4,532	$4,532	$4,532	$4,532	$4,532	$2,854
IC	Standard car	15%	15%	$4,713	$4,552	$4,552	$4,423	$4,423	$4,423	$4,423	$4,423	$2,786
IC	Standard car	20%	20%	$4,598	$4,440	$4,440	$4,314	$4,314	$4,314	$4,314	$4,314	$2,717
IC	Large car	10%	10%	$6,124	$5,915	$5,915	$5,747	$5,747	$5,747	$5,747	$5,747	$3,620
IC	Large car	15%	15%	$5,941	$5,738	$5,738	$5,575	$5,575	$5,575	$5,575	$5,575	$3,512
IC	Large car	20%	20%	$5,758	$5,561	$5,561	$5,403	$5,403	$5,403	$5,403	$5,403	$3,403
IC	Small MPV	10%	9%	$4,883	$4,715	$4,715	$4,582	$4,582	$4,582	$4,582	$4,582	$2,886
IC	Small MPV	15%	14%	$4,796	$4,632	$4,632	$4,501	$4,501	$4,501	$4,501	$4,501	$2,835
IC	Small MPV	20%	19%	$4,709	$4,548	$4,548	$4,419	$4,419	$4,419	$4,419	$4,419	$2,784
TC	Small car	10%	10%	$13,812	$11,738	$11,738	$10,079	$10,079	$10,079	$10,079	$10,079	$7,400
TC	Small car	15%	15%	$13,552	$11,518	$11,518	$9,890	$9,890	$9,890	$9,890	$9,890	$7,261
TC	Small car	20%	20%	$13,293	$11,297	$11,297	$9,700	$9,700	$9,700	$9,700	$9,700	$7,122
TC	Standard car	10%	10%	$16,055	$13,644	$13,644	$11,716	$11,716	$11,716	$11,716	$11,716	$8,602
TC	Standard car	15%	15%	$15,670	$13,317	$13,317	$11,435	$11,435	$11,435	$11,435	$11,435	$8,396
TC	Standard car	20%	20%	$15,285	$12,990	$12,990	$11,154	$11,154	$11,154	$11,154	$11,154	$8,190
TC	Large car	10%	10%	$20,360	$17,303	$17,303	$14,858	$14,858	$14,858	$14,858	$14,858	$10,909
TC	Large car	15%	15%	$19,752	$16,786	$16,786	$14,414	$14,414	$14,414	$14,414	$14,414	$10,583
TC	Large car	20%	20%	$19,144	$16,269	$16,269	$13,970	$13,970	$13,970	$13,970	$13,970	$10,257
TC	Small MPV	10%	9%	$16,232	$13,795	$13,795	$11,846	$11,846	$11,846	$11,846	$11,846	$8,697
TC	Small MPV	15%	14%	$15,945	$13,551	$13,551	$11,636	$11,636	$11,636	$11,636	$11,636	$8,543
TC	Small MPV	20%	19%	$15,657	$13,306	$13,306	$11,426	$11,426	$11,426	$11,426	$11,426	$8,389

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-84 Costs for EV75 Battery Packs for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	10%	$9,886	$7,909	$7,909	$6,327	$6,327	$6,327	$6,327	$6,327	$5,062
DMC	Small car	15%	15%	$9,718	$7,775	$7,775	$6,220	$6,220	$6,220	$6,220	$6,220	$4,976
DMC	Small car	20%	20%	$9,551	$7,640	$7,640	$6,112	$6,112	$6,112	$6,112	$6,112	$4,890
DMC	Standard car	10%	10%	$11,456	$9,164	$9,164	$7,332	$7,332	$7,332	$7,332	$7,332	$5,865
DMC	Standard car	15%	15%	$11,174	$8,939	$8,939	$7,151	$7,151	$7,151	$7,151	$7,151	$5,721
DMC	Standard car	20%	20%	$10,892	$8,713	$8,713	$6,971	$6,971	$6,971	$6,971	$6,971	$5,577
DMC	Large car	10%	10%	$14,592	$11,673	$11,673	$9,339	$9,339	$9,339	$9,339	$9,339	$7,471
DMC	Large car	15%	15%	$14,148	$11,318	$11,318	$9,055	$9,055	$9,055	$9,055	$9,055	$7,244
DMC	Large car	20%	20%	$13,704	$10,964	$10,964	$8,771	$8,771	$8,771	$8,771	$8,771	$7,017
DMC	Small MPV	10%	9%	$11,470	$9,176	$9,176	$7,341	$7,341	$7,341	$7,341	$7,341	$5,873
DMC	Small MPV	15%	14%	$11,260	$9,008	$9,008	$7,206	$7,206	$7,206	$7,206	$7,206	$5,765
DMC	Small MPV	20%	19%	$11,049	$8,840	$8,840	$7,072	$7,072	$7,072	$7,072	$7,072	$5,657

IC	Small car	10%	10%	$4,253	$4,107	$4,107	$3,991	$3,991	$3,991	$3,991	$3,991	$2,514
IC	Small car	15%	15%	$4,181	$4,038	$4,038	$3,923	$3,923	$3,923	$3,923	$3,923	$2,471
IC	Small car	20%	20%	$4,109	$3,968	$3,968	$3,855	$3,855	$3,855	$3,855	$3,855	$2,428
IC	Standard car	10%	10%	$4,928	$4,759	$4,759	$4,624	$4,624	$4,624	$4,624	$4,624	$2,913
IC	Standard car	15%	15%	$4,807	$4,642	$4,642	$4,511	$4,511	$4,511	$4,511	$4,511	$2,841
IC	Standard car	20%	20%	$4,685	$4,525	$4,525	$4,397	$4,397	$4,397	$4,397	$4,397	$2,769
IC	Large car	10%	10%	$6,277	$6,062	$6,062	$5,890	$5,890	$5,890	$5,890	$5,890	$3,710
IC	Large car	15%	15%	$6,086	$5,878	$5,878	$5,711	$5,711	$5,711	$5,711	$5,711	$3,597
IC	Large car	20%	20%	$5,895	$5,694	$5,694	$5,532	$5,532	$5,532	$5,532	$5,532	$3,485
IC	Small MPV	10%	9%	$4,934	$4,765	$4,765	$4,630	$4,630	$4,630	$4,630	$4,630	$2,917
IC	Small MPV	15%	14%	$4,844	$4,678	$4,678	$4,545	$4,545	$4,545	$4,545	$4,545	$2,863
IC	Small MPV	20%	19%	$4,753	$4,591	$4,591	$4,460	$4,460	$4,460	$4,460	$4,460	$2,809
TC	Small car	10%	10%	$14,139	$12,016	$12,016	$10,318	$10,318	$10,318	$10,318	$10,318	$7,575
TC	Small car	15%	15%	$13,899	$11,812	$11,812	$10,143	$10,143	$10,143	$10,143	$10,143	$7,447
TC	Small car	20%	20%	$13,659	$11,608	$11,608	$9,968	$9,968	$9,968	$9,968	$9,968	$7,318
TC	Standard car	10%	10%	$16,384	$13,924	$13,924	$11,956	$11,956	$11,956	$11,956	$11,956	$8,778
TC	Standard car	15%	15%	$15,980	$13,581	$13,581	$11,662	$11,662	$11,662	$11,662	$11,662	$8,562
TC	Standard car	20%	20%	$15,577	$13,238	$13,238	$11,367	$11,367	$11,367	$11,367	$11,367	$8,346
TC	Large car	10%	10%	$20,869	$17,736	$17,736	$15,229	$15,229	$15,229	$15,229	$15,229	$11,181
TC	Large car	15%	15%	$20,234	$17,196	$17,196	$14,766	$14,766	$14,766	$14,766	$14,766	$10,841
TC	Large car	20%	20%	$19,600	$16,657	$16,657	$14,303	$14,303	$14,303	$14,303	$14,303	$10,501
TC	Small MPV	10%	9%	$16,405	$13,942	$13,942	$11,971	$11,971	$11,971	$11,971	$11,971	$8,789
TC	Small MPV	15%	14%	$16,104	$13,686	$13,686	$11,752	$11,752	$11,752	$11,752	$11,752	$8,628
TC	Small MPV	20%	19%	$15,803	$13,430	$13,430	$11,532	$11,532	$11,532	$11,532	$11,532	$8,467

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-85 Costs for EV100 Battery Packs for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	4%	$11,774	$9,420	$9,420	$7,536	$7,536	$7,536	$7,536	$7,536	$6,028
DMC	Small car	15%	9%	$11,563	$9,250	$9,250	$7,400	$7,400	$7,400	$7,400	$7,400	$5,920
DMC	Small car	20%	14%	$11,351	$9,081	$9,081	$7,265	$7,265	$7,265	$7,265	$7,265	$5,812
DMC	Standard car	10%	4%	$13,550	$10,840	$10,840	$8,672	$8,672	$8,672	$8,672	$8,672	$6,938
DMC	Standard car	15%	9%	$13,261	$10,609	$10,609	$8,487	$8,487	$8,487	$8,487	$8,487	$6,790
DMC	Standard car	20%	14%	$12,973	$10,378	$10,378	$8,302	$8,302	$8,302	$8,302	$8,302	$6,642
DMC	Large car	10%	5%	$16,403	$13,122	$13,122	$10,498	$10,498	$10,498	$10,498	$10,498	$8,398
DMC	Large car	15%	10%	$15,949	$12,759	$12,759	$10,207	$10,207	$10,207	$10,207	$10,207	$8,166
DMC	Large car	20%	15%	$15,495	$12,396	$12,396	$9,917	$9,917	$9,917	$9,917	$9,917	$7,933
DMC	Small MPV	10%	3%	$14,089	$11,271	$11,271	$9,017	$9,017	$9,017	$9,017	$9,017	$7,214

DMC	Small MPV	15%	8%	$13,830	$11,064	$11,064	$8,851	$8,851	$8,851	$8,851	$8,851	$7,081
DMC	Small MPV	20%	13%	$13,572	$10,857	$10,857	$8,686	$8,686	$8,686	$8,686	$8,686	$6,949
IC	Small car	10%	4%	$5,065	$4,892	$4,892	$4,753	$4,753	$4,753	$4,753	$4,753	$2,994
IC	Small car	15%	9%	$4,974	$4,804	$4,804	$4,668	$4,668	$4,668	$4,668	$4,668	$2,940
IC	Small car	20%	14%	$4,883	$4,716	$4,716	$4,582	$4,582	$4,582	$4,582	$4,582	$2,886
IC	Standard car	10%	4%	$5,829	$5,630	$5,630	$5,470	$5,470	$5,470	$5,470	$5,470	$3,445
IC	Standard car	15%	9%	$5,705	$5,510	$5,510	$5,353	$5,353	$5,353	$5,353	$5,353	$3,372
IC	Standard car	20%	14%	$5,581	$5,390	$5,390	$5,237	$5,237	$5,237	$5,237	$5,237	$3,298
IC	Large car	10%	5%	$7,056	$6,815	$6,815	$6,621	$6,621	$6,621	$6,621	$6,621	$4,171
IC	Large car	15%	10%	$6,861	$6,626	$6,626	$6,438	$6,438	$6,438	$6,438	$6,438	$4,055
IC	Large car	20%	15%	$6,666	$6,438	$6,438	$6,255	$6,255	$6,255	$6,255	$6,255	$3,940
IC	Small MPV	10%	3%	$6,061	$5,853	$5,853	$5,687	$5,687	$5,687	$5,687	$5,687	$3,582
IC	Small MPV	15%	8%	$5,950	$5,746	$5,746	$5,583	$5,583	$5,583	$5,583	$5,583	$3,517
IC	Small MPV	20%	13%	$5,838	$5,638	$5,638	$5,479	$5,479	$5,479	$5,479	$5,479	$3,451
TC	Small car	10%	4%	$16,840	$14,311	$14,311	$12,289	$12,289	$12,289	$12,289	$12,289	$9,022
TC	Small car	15%	9%	$16,537	$14,054	$14,054	$12,068	$12,068	$12,068	$12,068	$12,068	$8,860
TC	Small car	20%	14%	$16,234	$13,797	$13,797	$11,847	$11,847	$11,847	$11,847	$11,847	$8,698
TC	Standard car	10%	4%	$19,380	$16,470	$16,470	$14,142	$14,142	$14,142	$14,142	$14,142	$10,383
TC	Standard car	15%	9%	$18,966	$16,119	$16,119	$13,841	$13,841	$13,841	$13,841	$13,841	$10,162
TC	Standard car	20%	14%	$18,553	$15,768	$15,768	$13,539	$13,539	$13,539	$13,539	$13,539	$9,940
TC	Large car	10%	5%	$23,459	$19,937	$19,937	$17,119	$17,119	$17,119	$17,119	$17,119	$12,569
TC	Large car	15%	10%	$22,810	$19,385	$19,385	$16,645	$16,645	$16,645	$16,645	$16,645	$12,221
TC	Large car	20%	15%	$22,161	$18,833	$18,833	$16,172	$16,172	$16,172	$16,172	$16,172	$11,873
TC	Small MPV	10%	3%	$20,150	$17,125	$17,125	$14,705	$14,705	$14,705	$14,705	$14,705	$10,796
TC	Small MPV	15%	8%	$19,780	$16,810	$16,810	$14,434	$14,434	$14,434	$14,434	$14,434	$10,598
TC	Small MPV	20%	13%	$19,410	$16,496	$16,496	$14,164	$14,164	$14,164	$14,164	$14,164	$10,399

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-86 Costs for EV100 Battery Packs for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	4%	$12,046	$9,637	$9,637	$7,710	$7,710	$7,710	$7,710	$7,710	$6,168
DMC	Small car	15%	9%	$11,831	$9,465	$9,465	$7,572	$7,572	$7,572	$7,572	$7,572	$6,057
DMC	Small car	20%	14%	$11,615	$9,292	$9,292	$7,434	$7,434	$7,434	$7,434	$7,434	$5,947
DMC	Standard car	10%	4%	$13,794	$11,035	$11,035	$8,828	$8,828	$8,828	$8,828	$8,828	$7,062
DMC	Standard car	15%	9%	$13,512	$10,810	$10,810	$8,648	$8,648	$8,648	$8,648	$8,648	$6,918
DMC	Standard car	20%	14%	$13,231	$10,585	$10,585	$8,468	$8,468	$8,468	$8,468	$8,468	$6,774
DMC	Large car	10%	5%	$16,845	$13,476	$13,476	$10,781	$10,781	$10,781	$10,781	$10,781	$8,625
DMC	Large car	15%	10%	$16,382	$13,106	$13,106	$10,484	$10,484	$10,484	$10,484	$10,484	$8,388
DMC	Large car	20%	15%	$15,919	$12,735	$12,735	$10,188	$10,188	$10,188	$10,188	$10,188	$8,150
DMC	Small MPV	10%	3%	$14,246	$11,397	$11,397	$9,117	$9,117	$9,117	$9,117	$9,117	$7,294
DMC	Small MPV	15%	8%	$13,982	$11,185	$11,185	$8,948	$8,948	$8,948	$8,948	$8,948	$7,159
DMC	Small MPV	20%	13%	$13,718	$10,974	$10,974	$8,779	$8,779	$8,779	$8,779	$8,779	$7,023
IC	Small car	10%	4%	$5,182	$5,005	$5,005	$4,863	$4,863	$4,863	$4,863	$4,863	$3,063
IC	Small car	15%	9%	$5,089	$4,915	$4,915	$4,776	$4,776	$4,776	$4,776	$4,776	$3,008

IC	Small car	20%	14%	$4,997	$4,826	$4,826	$4,689	$4,689	$4,689	$4,689	$4,689	$2,953
IC	Standard car	10%	4%	$5,934	$5,731	$5,731	$5,568	$5,568	$5,568	$5,568	$5,568	$3,507
IC	Standard car	15%	9%	$5,813	$5,614	$5,614	$5,455	$5,455	$5,455	$5,455	$5,455	$3,436
IC	Standard car	20%	14%	$5,692	$5,497	$5,497	$5,341	$5,341	$5,341	$5,341	$5,341	$3,364
IC	Large car	10%	5%	$7,247	$6,999	$6,999	$6,800	$6,800	$6,800	$6,800	$6,800	$4,283
IC	Large car	15%	10%	$7,047	$6,806	$6,806	$6,613	$6,613	$6,613	$6,613	$6,613	$4,165
IC	Large car	20%	15%	$6,848	$6,614	$6,614	$6,426	$6,426	$6,426	$6,426	$6,426	$4,048
IC	Small MPV	10%	3%	$6,128	$5,919	$5,919	$5,751	$5,751	$5,751	$5,751	$5,751	$3,622
IC	Small MPV	15%	8%	$6,015	$5,809	$5,809	$5,644	$5,644	$5,644	$5,644	$5,644	$3,555
IC	Small MPV	20%	13%	$5,901	$5,699	$5,699	$5,538	$5,538	$5,538	$5,538	$5,538	$3,488
TC	Small car	10%	4%	$17,229	$14,642	$14,642	$12,573	$12,573	$12,573	$12,573	$12,573	$9,231
TC	Small car	15%	9%	$16,920	$14,380	$14,380	$12,348	$12,348	$12,348	$12,348	$12,348	$9,066
TC	Small car	20%	14%	$16,612	$14,118	$14,118	$12,122	$12,122	$12,122	$12,122	$12,122	$8,900
TC	Standard car	10%	4%	$19,728	$16,766	$16,766	$14,396	$14,396	$14,396	$14,396	$14,396	$10,570
TC	Standard car	15%	9%	$19,325	$16,424	$16,424	$14,103	$14,103	$14,103	$14,103	$14,103	$10,354
TC	Standard car	20%	14%	$18,923	$16,082	$16,082	$13,809	$13,809	$13,809	$13,809	$13,809	$10,138
TC	Large car	10%	5%	$24,092	$20,475	$20,475	$17,581	$17,581	$17,581	$17,581	$17,581	$12,908
TC	Large car	15%	10%	$23,429	$19,912	$19,912	$17,097	$17,097	$17,097	$17,097	$17,097	$12,553
TC	Large car	20%	15%	$22,767	$19,348	$19,348	$16,614	$16,614	$16,614	$16,614	$16,614	$12,198
TC	Small MPV	10%	3%	$20,375	$17,316	$17,316	$14,868	$14,868	$14,868	$14,868	$14,868	$10,916
TC	Small MPV	15%	8%	$19,997	$16,994	$16,994	$14,593	$14,593	$14,593	$14,593	$14,593	$10,714
TC	Small MPV	20%	13%	$19,619	$16,673	$16,673	$14,317	$14,317	$14,317	$14,317	$14,317	$10,511

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-87 Costs for EV150 Battery Packs for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	20%	2%	$15,701	$12,561	$12,561	$10,049	$10,049	$10,049	$10,049	$10,049	$8,039
DMC	Standard car	20%	2%	$18,950	$15,160	$15,160	$12,128	$12,128	$12,128	$12,128	$12,128	$9,702
DMC	Large car	20%	3%	$21,552	$17,242	$17,242	$13,793	$13,793	$13,793	$13,793	$13,793	$11,035
DMC	Small MPV	20%	1%	$19,744	$15,795	$15,795	$12,636	$12,636	$12,636	$12,636	$12,636	$10,109
IC	Small car	20%	2%	$6,755	$6,523	$6,523	$6,338	$6,338	$6,338	$6,338	$6,338	$3,992
IC	Standard car	20%	2%	$8,152	$7,873	$7,873	$7,650	$7,650	$7,650	$7,650	$7,650	$4,818
IC	Large car	20%	3%	$9,272	$8,954	$8,954	$8,700	$8,700	$8,700	$8,700	$8,700	$5,480
IC	Small MPV	20%	1%	$8,493	$8,203	$8,203	$7,970	$7,970	$7,970	$7,970	$7,970	$5,020
TC	Small car	20%	2%	$22,456	$19,084	$19,084	$16,387	$16,387	$16,387	$16,387	$16,387	$12,031
TC	Standard car	20%	2%	$27,102	$23,033	$23,033	$19,777	$19,777	$19,777	$19,777	$19,777	$14,520
TC	Large car	20%	3%	$30,824	$26,196	$26,196	$22,494	$22,494	$22,494	$22,494	$22,494	$16,515
TC	Small MPV	20%	1%	$28,237	$23,998	$23,998	$20,606	$20,606	$20,606	$20,606	$20,606	$15,129

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-88 Costs for EV150 Battery Packs for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	20%	2%	$16,102	$12,881	$12,881	$10,305	$10,305	$10,305	$10,305	$10,305	$8,244
DMC	Standard car	20%	2%	$19,265	$15,412	$15,412	$12,329	$12,329	$12,329	$12,329	$12,329	$9,863
DMC	Large car	20%	3%	$22,080	$17,664	$17,664	$14,131	$14,131	$14,131	$14,131	$14,131	$11,305
DMC	Small MPV	20%	1%	$19,976	$15,981	$15,981	$12,784	$12,784	$12,784	$12,784	$12,784	$10,228
IC	Small car	20%	2%	$6,927	$6,690	$6,690	$6,500	$6,500	$6,500	$6,500	$6,500	$4,094
IC	Standard car	20%	2%	$8,287	$8,004	$8,004	$7,777	$7,777	$7,777	$7,777	$7,777	$4,898
IC	Large car	20%	3%	$9,498	$9,173	$9,173	$8,913	$8,913	$8,913	$8,913	$8,913	$5,614
IC	Small MPV	20%	1%	$8,593	$8,299	$8,299	$8,064	$8,064	$8,064	$8,064	$8,064	$5,079
TC	Small car	20%	2%	$23,028	$19,571	$19,571	$16,805	$16,805	$16,805	$16,805	$16,805	$12,338
TC	Standard car	20%	2%	$27,552	$23,415	$23,415	$20,106	$20,106	$20,106	$20,106	$20,106	$14,762
TC	Large car	20%	3%	$31,578	$26,837	$26,837	$23,044	$23,044	$23,044	$23,044	$23,044	$16,919
TC	Small MPV	20%	1%	$28,569	$24,280	$24,280	$20,848	$20,848	$20,848	$20,848	$20,848	$15,307

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

For Mild HEV batteries, the agencies used a similar approach to estimating the cost of the battery pack but used a different approach to determining its size. Our Mild HEV system used in the analyses is based, largely, on the Buick eAssist system.[yy] According to the press releases, it includes a 15 kW motor and a 15 kW/0.5kWh/115 Volt two-module battery. For the agencies' analyses, a 15kW/0.25kWh/110 Volt single-module battery was selected for several reasons. First, the Buick system uses a 20% state-of-charge (SOC) swing for the battery. We believe that, in the 2017-2025 timeframe, a 40% SOC swing is reasonable. As such, the energy capacity of the battery can be halved (from 0.5 to 0.25 kWh).[zz] The 110V system used in the analysis is essentially the same as Buick's 115V system. The voltage change is due to our use of a 28 cell single-module battery pack rather than the 32 cell double-module battery pack which is used in the eAssist system. Such changes are consistent with our expectation that cells will increase in size allowing for fewer cells and fewer modules. Further, for the Mild HEV technology, the agencies are using the same system regardless of vehicle class or subclass. In other words, the Mild HEV system is a stand-alone technology that can be applied to any subclass without unique modifications for each class or subclass. As such, it adds more weight as a percentage to a smaller vehicle than to a larger vehicle but it provides more effectiveness to a smaller vehicle than to a larger vehicle. Since the same system is used regardless of vehicle class or subclass, the costs are identical regardless of vehicle class or subclass. Using the ANL BatPaC model, the Mild HEV battery DMC was calculated as $553 and is considered applicable to the MY 2017. The agencies derived the Mild HEV battery pack cost using the same methodology that was used for the P2 HEV

[yy] "eAssist" is a Buick (or General Motors) term and is not a generic term for this technology, hence our use of the term mild hybrid.

[zz] Note that projected battery cost is relatively insensitive to kWh capacity at the high power-to-energy ratio of these batteries. A 0.5 kWh battery could alternatively be specified at a similar cost.

battery pack, and consider cost to be on the flat portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a high1 complexity ICM of 1.56 through 2024 then 1.35 thereafter. The resultant Mild HEV battery pack costs are as shown in Table 3-89. The associated weight penalties are as shown in Table 3-90.

Table 3-89 Costs for Mild Hybrid (MHEV) Battery Packs for both the 2008 and 2010 Baselines (2010$)

Cost type	Vehicle class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	$553	$536	$520	$505	$490	$475	$461	$447	$433
IC	All	$312	$311	$310	$309	$308	$307	$306	$305	$187
TC	All	$865	$847	$830	$813	$797	$782	$766	$752	$621

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-90 EPA and NHTSA Weight Reduction Offset Associated with MHEV for both the 2008 and 2010 Baselines

Vehicle class	Weight penalty
Small car	3.5%
Standard car	3.0%
Large car	2.5%
Small MPV	2.5%
Large MPV	2.5%
Truck	2.0%

The CAFE model does not use pre-built packages and it applies technologies incrementally as necessary to meet the fuel consumption reduction requirement, so the cost interaction between any particular technology and other technologies (cost synergies) must be defined. This allows flexibility so that when a technology is picked, the model will automatically look through the cost synergy defined in a table and apply cost adjustments accordingly. The total cost for mass reduction and electrification is composed of the following four parts:

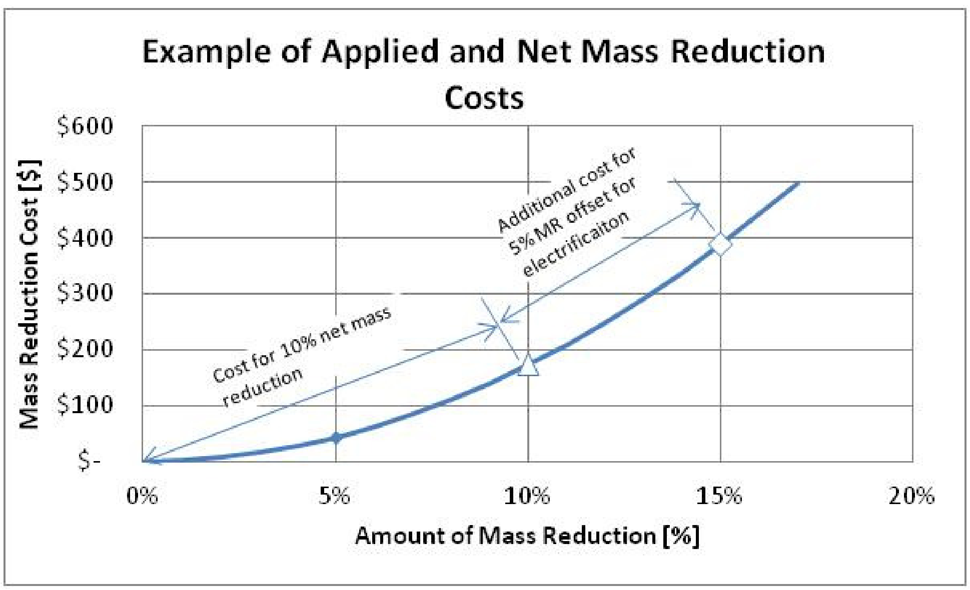
(1) Cost of net mass reduction;
(2) Cost of electrification with zero mass reduction;
(3) Mass reduction cost synergy for increased or decreased amount of mass reduction due to switching from conventional powertrain to electrification systems as defined in Figure 3-25. For an example, if a midsize passenger car needs both 10 percent net mass reduction and P2 hybrid to meet the CAFE target, the model will need to find the cost of additional 5 percent of mass reduction to consider the vehicle weight increase due to switching from conventional powertrain system to P2 electrification packages. This additional 5 percent of mass reduction is calculated starting from 10 percent mass reduction, not zero as shown in Figure 3-25 because mass reduction cost versus mass reduction percent is not a linear function. The cost increases faster as the

amount of mass reduction becomes higher.

(4) Electrification system cost synergies (battery and non-battery components) due to mass reduction as defined in Table 3-76 and Table 3-103: Continuing the example in the steps above, if a midsize passenger car needs both10 percent net mass reduction and P2 hybrid to meet the CAFE target, after calculating the costs above, the model will need to find the cost of electrification systems, including battery system and non-battery system, with the required net amount of mass reduction using the equations in Table 3-76 and Table 3-103. Then the delta cost between this cost and the cost calculated in step 2, i.e. electrification system cost with zero applied mass reduction is calculated and treated as a cost synergy. These cost deltas are normally negative, i.e., a cost reduction, due to the downsizing of the electrification system resulting from mass reduction

The sum of item (3) and (4) in the above list are calculated as cost synergies and stored in the cost synergy table as defined in NHTSA's RIA.

Figure 3-25 Mass Reduction Cost Example for Applied and Net Mass Reduction



The agencies have also carefully reconsidered the power and energy requirements for each electrified vehicle type, which has a significant impact on the cost estimates for HEVs, PHEVs, and EVs as compared to the estimates used in the 2012-2016 rulemaking.

The agencies note that, for this analysis, the agencies have assumed batteries will be capable of lasting the lifetime of the vehicle, which is consistent with the expected customer demands from this technology (as manufacturers have confirmed). Lastly, the agencies have focused attention on an emerging HEV technology known as a P2-hybrid, a technology not considered in the 2012-2016 light-duty rule.

The agencies have also considered, for this analysis, the costs associated with in-home chargers expected to be necessary for PHEVs and EVs. Further details on in-home chargers and their estimated costs are presented in Section 3.4.4.

3.4.3.10 Non-battery costs for MHEVs, HEVs, PHEVs, EVs and FCEVs

This section addresses the costs of non-battery components which are required for electric drive vehicles. Some of these components are not found in every electric-drive vehicle (e.g. an HEV does not have an on-board battery charger as found in a PHEV or EV). Others are found in all electric drive vehicles and/or must be scaled to the vehicle type or class to properly represent the cost. The agencies derived the costs of these components from the FEV teardown study and the 2010 TAR. Where appropriate, costs were scaled to vehicle class and in the case of the motor and inverter, the sizing methodology used for battery sizing was applied.

The electric drive motor and inverter provide the motive power for any electric-drive vehicle converting electrical energy from the battery into kinetic energy for propulsion. In an electric-drive vehicle, energy stored in the battery is routed to the inverter which converts it to a voltage and wave form that can be used by the motor.

In many cases, such as HEVs, the combined cost of the motor and inverter exceed the battery cost. As batteries become larger in PHEVs and EVs, the battery cost grows faster than motor and inverter cost. For this analysis, the agencies used the vehicle power requirement calculation discussed in 3.4.3.8 to calculate the required motor and inverter size for each vehicle class at each weight reduction point. Then, for the HEVs and PHEVs, a regression was created from the FEV teardown data for motors and inverters and this regression was used to calculate the motor and inverter cost for each combination of vehicle class and weight reduction. This regression for use with the 2008 baseline was $13.78x(motor size in kW)+$781.50 (values in 2010$), and for use with the 2010 baseline was $14.13x(motor size in kW)+$771.21 (values in 2010$). The results are shown as the "Motor assembly" line item in Table 3-91 through Table 3-96, which show our scaled DMC for P2 HEV, PHEV20 and PHEV40, respectively, for both the 2008 and 2010 baselines.

For EVs, the agencies used the motor and inverter cost regression from the 2010 TAR (see 2010 TAR at page B-21) and we used that regression for both the 2008 and 2010 baselines. Since the FEV teardown was conducted on an HEV Ford Fusion, the agencies believe the technology for an EV is different enough to warrant using the TAR regression. The regression presented in the TAR showed the DMC being equal to $8.45x(motor size in kW)+$185.05 (values in 2010$). The results are presented as separate line items for "Motor inverter" and "Motor assembly" in Table 3-97 through Table 3-102, which show our scaled DMC for EV75, EV100 and EV150, respectively, for both the 2008 and 2010 baselines.

In addition to electric drive motors and inverters, there are several other components in electric drive vehicles that are required. These components include the following:

- *Body Modifications* which are required on HEVs and PHEVs include changes to sheet metal to accommodate electric drive components and the addition of fasteners to secure components such as electric cables. These costs come from the FEV teardown and are scaled by vehicle class. For EVs, these costs are assumed to be included in the base vehicle because they are less likely to be adapted from conventional vehicles.

- *Brake System* changes include the addition of a braking system that can control the vehicle's regenerative braking system—a key enabler of electric drive vehicle efficiency. The brake system costs are from the FEV teardown and are scaled to vehicle class.

- *Climate Control System* includes components such as an electric air conditioning compressor that enables operation while the engine is off for HEVs and PHEVs as well as for an EV which has no engine. Climate control system costs come from the FEV teardown and are scaled to vehicle class.

- *Conventional vehicle battery and alternator* are deleted in these vehicles, for a cost savings, replaced by the DC-DC converter which converts the high-voltage traction battery to a nominal 12V DC to operate the vehicle's accessories. This credit comes from the FEV teardown study and is scaled to vehicle class.

- *DC-DC converter* converts the high-voltage battery voltage to a nominal 12V battery voltage to run vehicle accessories such as the radio, lights and wipers. This cost comes from the FEV teardown study and is scaled to vehicle class.

- *Power distribution and Control* consists of those components which route electricity to the motor, inverter and contains the controllers to operate and monitor the electric drive system. This cost applies to HEVs and PHEVs and comes from the FEV teardown study. It is scaled to vehicle class.

- *On-Vehicle Charger* consists of the components necessary to charge a PHEV or EV from an outlet. It includes the charging port, wiring and electronics necessary to convert a 120V or 240V AC input to the high-voltage DC power necessary to charge the battery. Because the FEV teardown study subject vehicle did not have an on-vehicle charger, the costs from the TAR were used for this item. It is not scaled to vehicle class, however the EV charger is assumed to cost twice the amount of the PHEV charger to account for a higher current capacity. This cost does not include off-vehicle charger components which are discussed in Section 3.4.4, below.

- *Supplemental heating* is required for passenger comfort on PHEVs and EVs which may operate for long periods with no engine heat available. This cost comes from the FEV teardown study and is scaled to vehicle class. The supplemental heater on the EV is assumed to be three times more costly than the PHEV because the entire cabin comfort is dependent on the supplemental heater. In a PHEV, it is assumed that in extreme conditions, the internal combustion engine will start to provide additional cabin heat and defrost functions.

- *High Voltage Wiring* is an item used on EVs only. It includes the high voltage cabling from the battery to the inverter and motor as well as control components. It is equivalent to the power distribution and control used on HEVs and PHEVs and comes from the FEV teardown study. It is scaled to vehicle class.

- *Delete Internal Combustion Engine and Transmission* For EVs, the engine and transmission are deleted and a credit is applied. These credits come from work done in support of the 2010 TAR and are scaled to vehicle class.

- *Battery Discharge System* For HEVs, PHEVs and EVs, it is expected that manufacturers will provide the means to safely discharge battery packs following a vehicle crash. The agencies have assumed that this would include dedicated DC terminals, an access panel for the terminals, and a diagnostics port. The estimated cost of this capability is the same for all vehicle classes, but is different for HEVs than for PHEVs and EVs.

The results of the scaling exercise applied to non-battery components are presented in Table 3-91 through Table 3-102 for P2 HEVs, PHEV20, PHEV40, EV75, EV100 and EV150, for the 2008 and 2010 baselines, respectively.

Table 3-91 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for P2 HEV for the 2008 Baseline (2010$)

System	Small car	Standard car	Large car	Small MPV	Large MPV	Truck
0% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$221	$228	$231	$225	$233	$240
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$162	$152	$152	$177
Power Distr & control	$196	$201	$204	$200	$206	$220
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,045	$1,172	$1,480	$1,112	$1,287	$1,429
Total	$1,675	$1,857	$2,175	$1,777	$2,052	$2,169
2% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$221	$228	$231	$225	$233	$240
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$162	$152	$152	$177
Power Distr & control	$196	$201	$204	$200	$206	$220
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,039	$1,164	$1,467	$1,106	$1,277	$1,416
Total	$1,670	$1,849	$2,161	$1,771	$2,042	$2,156
7.5% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$221	$228	$231	$225	$233	$240
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$162	$152	$152	$177
Power Distr & control	$196	$201	$204	$200	$206	$220
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,025	$1,143	$1,428	$1,088	$1,249	$1,381
Total	$1,655	$1,828	$2,123	$1,752	$2,014	$2,121
10% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$221	$228	$231	$225	$233	$240
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$162	$152	$152	$177
Power Distr & control	$196	$201	$204	$200	$206	$220
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,018	$1,133	$1,411	$1,079	$1,237	$1,364

Total	$1,649	$1,818	$2,105	$1,744	$2,002	$2,104
20% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$221	$228	$231	$225	$233	$240
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$162	$152	$152	$177
Power Distr & control	$196	$201	$204	$200	$206	$220
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,007	$1,115	$1,377	$1,064	$1,212	$1,337
Total	$1,637	$1,800	$2,071	$1,729	$1,977	$2,077

Table 3-92 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for P2 HEV for the 2010 Baseline (2010$)

System	Small car	Standard car	Large car	Small MPV	Large MPV	Truck
0% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$223	$229	$232	$225	$232	$242
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$177	$162	$162	$177
Power Distr & control	$197	$202	$205	$201	$206	$221
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,051	$1,191	$1,512	$1,134	$1,299	$1,445
Total	$1,683	$1,878	$2,224	$1,811	$2,073	$2,188
2% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$223	$229	$232	$225	$232	$242
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$177	$162	$162	$177
Power Distr & control	$197	$202	$205	$201	$206	$221
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,045	$1,183	$1,497	$1,127	$1,288	$1,432
Total	$1,677	$1,869	$2,210	$1,804	$2,063	$2,175
7.5% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$223	$229	$232	$225	$232	$242
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$177	$162	$162	$177
Power Distr & control	$197	$202	$205	$201	$206	$221
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,030	$1,159	$1,457	$1,107	$1,259	$1,395
Total	$1,662	$1,846	$2,169	$1,784	$2,034	$2,138
10% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$223	$229	$232	$225	$232	$242
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$177	$162	$162	$177
Power Distr & control	$197	$202	$205	$201	$206	$221

Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,023	$1,149	$1,438	$1,098	$1,246	$1,378
Total	$1,655	$1,836	$2,150	$1,775	$2,021	$2,121
20% WR						
Body system	$6	$6	$6	$6	$6	$6
Brake system	$223	$229	$232	$225	$232	$242
Climate controls	$140	$157	$168	$164	$250	$186
Delete electrical	-$60	-$65	-$82	-$86	-$86	-$94
DC-DC converter	$121	$152	$177	$162	$162	$177
Power Distr & control	$197	$202	$205	$201	$206	$221
Battery discharge system	$6	$6	$6	$6	$6	$6
Motor assembly	$1,010	$1,129	$1,402	$1,081	$1,220	$1,350
Total	$1,642	$1,816	$2,114	$1,757	$1,994	$2,093

Table 3-93 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for PHEV20 for the 2008 Baseline (2010$)

System	Small car	Standard car	Large car	Small MPV
0% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,097	$2,735	$4,276	$2,436
Battery discharge system	$13	$13	$13	$13
Total	$2,878	$3,575	$5,129	$3,258
2% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,071	$2,695	$4,207	$2,403
Battery discharge system	$13	$13	$13	$13
Total	$2,852	$3,536	$5,059	$3,225
7.5% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$1,999	$2,588	$4,014	$2,312
Battery discharge system	$13	$13	$13	$13

Total	$2,780	$3,428	$4,867	$3,134
10% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$1,966	$2,539	$3,927	$2,271
Battery discharge system	$13	$13	$13	$13
Total	$2,747	$3,379	$4,780	$3,093
20% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$1,943	$2,500	$3,861	$2,235
Battery discharge system	$13	$13	$13	$13
Total	$2,724	$3,341	$4,714	$3,057

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-94 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for PHEV20 for the 2010 Baseline (2010$)

System	Small car	Standard car	Large car	Small MPV
0% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,169	$2,870	$4,476	$2,586
Battery discharge system	$13	$13	$13	$13
Total	$2,951	$3,712	$5,347	$3,419
2% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,141	$2,828	$4,402	$2,549

Battery discharge system	$13	$13	$13	$13
Total	$2,924	$3,670	$5,272	$3,383
7.5% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,064	$2,712	$4,198	$2,450
Battery discharge system	$13	$13	$13	$13
Total	$2,847	$3,554	$5,069	$3,283
10% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,029	$2,660	$4,106	$2,404
Battery discharge system	$13	$13	$13	$13
Total	$2,812	$3,502	$4,976	$3,238
20% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,002	$2,616	$4,031	$2,364
Battery discharge system	$13	$13	$13	$13
Total	$2,785	$3,458	$4,901	$3,197

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-95 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for PHEV40 for the 2008 Baseline (2010$)

System	Small car	Standard car	Large car	Small MPV
0% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105

Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,097	$2,735	$4,276	$2,436
Battery discharge system	$13	$13	$13	$13
Total	$2,878	$3,575	$5,129	$3,258
2% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,071	$2,695	$4,207	$2,403
Battery discharge system	$13	$13	$13	$13
Total	$2,852	$3,536	$5,059	$3,225
7.5% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,007	$2,591	$4,025	$2,313
Battery discharge system	$13	$13	$13	$13
Total	$2,788	$3,432	$4,878	$3,135
10% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,007	$2,591	$4,025	$2,312
Battery discharge system	$13	$13	$13	$13
Total	$2,788	$3,432	$4,878	$3,134
20% WR				
Body system	$6	$6	$6	$6
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
Power Distr & control	$196	$201	$204	$200
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,007	$2,591	$4,025	$2,312
Battery discharge system	$13	$13	$13	$13
Total	$2,788	$3,432	$4,878	$3,134

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-96 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for PHEV40 for the 2010 Baseline (2010$) [a]

System	Small car	Standard car	Large car	Small MPV
0% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,169	$2,870	$4,476	$2,586
Battery discharge system	$13	$13	$13	$13
Total	$2,951	$3,712	$5,347	$3,419
2% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,141	$2,828	$4,402	$2,549
Battery discharge system	$13	$13	$13	$13
Total	$2,924	$3,670	$5,272	$3,383
7.5% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,068	$2,714	$4,206	$2,450
Battery discharge system	$13	$13	$13	$13
Total	$2,851	$3,556	$5,076	$3,283
10% WR				
Body system	$6	$6	$6	$6
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,068	$2,714	$4,206	$2,449
Battery discharge system	$13	$13	$13	$13
Total	$2,851	$3,556	$5,076	$3,283
20% WR				
Body system	$6	$6	$6	$6

Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
Power Distr & control	$197	$202	$205	$201
On vehicle charger	$105	$105	$105	$105
Supplemental heater	$38	$43	$45	$44
Motor assembly	$2,068	$2,714	$4,206	$2,449
Battery discharge system	$13	$13	$13	$13
Total	$2,851	$3,556	$5,076	$3,283

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-97 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV75 for the 2008 Baseline (2010$) [a]

System	Small car	Standard car	Large car	Small MPV
0% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$703	$1,044	$1,868	$885
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$992	$1,383	$2,329	$1,200
Battery discharge system	$13	$13	$13	$13
Total	$350	$1,145	$2,060	-$12
2% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$689	$1,023	$1,831	$867
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$976	$1,359	$2,286	$1,180
Battery discharge system	$13	$13	$13	$13
Total	$320	$1,100	$1,979	-$50
7.5% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89

On vehicle charger	$316	$316	$316	$316
Motor inverter	$650	$966	$1,728	$818
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$932	$1,293	$2,168	$1,124
Battery discharge system	$13	$13	$13	$13
Total	$237	$977	$1,759	-$154
10% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$633	$939	$1,681	$796
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$911	$1,263	$2,114	$1,099
Battery discharge system	$13	$13	$13	$13
Total	$199	$921	$1,659	-$202
20% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$571	$851	$1,519	$727
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$840	$1,162	$1,928	$1,020
Battery discharge system	$13	$13	$13	$13
Total	$65	$731	$1,309	-$350

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-98 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV75 for the 2010 Baseline (2010$) [a]

System	Small car	Standard car	Large car	Small MPV
0% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$729	$1,094	$1,932	$946

Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,021	$1,441	$2,402	$1,271
Battery discharge system	$13	$13	$13	$13
Total	$406	$1,255	$2,214	$132
2% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$714	$1,072	$1,893	$927
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,004	$1,416	$2,358	$1,249
Battery discharge system	$13	$13	$13	$13
Total	$375	$1,208	$2,131	$92
7.5% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$674	$1,012	$1,787	$875
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$958	$1,347	$2,236	$1,189
Battery discharge system	$13	$13	$13	$13
Total	$289	$1,079	$1,903	-$20
10% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$656	$985	$1,739	$851
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$938	$1,315	$2,180	$1,162
Battery discharge system	$13	$13	$13	$13
Total	$250	$1,020	$1,799	-$71
20% WR				
Brake system	$223	$229	$232	$225

Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$595	$895	$1,580	$780
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$867	$1,212	$1,998	$1,080
Battery discharge system	$13	$13	$13	$13
Total	$118	$828	$1,458	-$225

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-99 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV100 for the 2008 Baseline (2010$) [a]

System	Small car	Standard car	Large car	Small MPV
0% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$703	$1,044	$1,868	$885
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$992	$1,383	$2,329	$1,200
Battery discharge system	$13	$13	$13	$13
Total	$350	$1,145	$2,060	-$12
2% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$689	$1,023	$1,831	$867
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$976	$1,359	$2,286	$1,180
Battery discharge system	$13	$13	$13	$13
Total	$320	$1,100	$1,979	-$50
7.5% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86

DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$650	$966	$1,728	$818
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$932	$1,293	$2,168	$1,124
Battery discharge system	$13	$13	$13	$13
Total	$237	$977	$1,759	-$154
10% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$633	$939	$1,681	$796
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$911	$1,263	$2,114	$1,099
Battery discharge system	$13	$13	$13	$13
Total	$199	$921	$1,659	-$202
20% WR				
Brake system	$221	$228	$231	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$608	$906	$1,617	$774
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$883	$1,224	$2,041	$1,073
Battery discharge system	$13	$13	$13	$13
Total	$146	$848	$1,521	-$249

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-100 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV100 for the 2010 Baseline (2010$) [a]

System	Small car	Standard car	Large car	Small MPV
0% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201

Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$729	$1,094	$1,932	$946
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,021	$1,441	$2,402	$1,271
Battery discharge system	$13	$13	$13	$13
Total	$406	$1,255	$2,214	$132
2% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$714	$1,072	$1,893	$927
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,004	$1,416	$2,358	$1,249
Battery discharge system	$13	$13	$13	$13
Total	$375	$1,208	$2,131	$92
7.5% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$674	$1,012	$1,787	$875
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$958	$1,347	$2,236	$1,189
Battery discharge system	$13	$13	$13	$13
Total	$289	$1,079	$1,903	-$20
10% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$656	$985	$1,739	$851
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$938	$1,315	$2,180	$1,162
Battery discharge system	$13	$13	$13	$13

Total	$250	$1,020	$1,799	-$71
20% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$633	$954	$1,684	$829
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$912	$1,280	$2,118	$1,137
Battery discharge system	$13	$13	$13	$13
Total	$201	$954	$1,682	-$118

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-101 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV150 for the 2008 Baseline (2010$) [a]

System	Small car	Standard car	Large car	Small MPV
0% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$703	$1,044	$1,868	$885
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$992	$1,383	$2,329	$1,200
Battery discharge system	$13	$13	$13	$13
Total	$351	$1,146	$2,061	-$11
2% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$692	$1,028	$1,837	$878
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$979	$1,364	$2,293	$1,193
Battery discharge system	$13	$13	$13	$13
Total	$328	$1,111	$1,995	-$26
7.5% WR				

Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$692	$1,028	$1,837	$878
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$979	$1,364	$2,293	$1,193
Battery discharge system	$13	$13	$13	$13
Total	$328	$1,111	$1,995	-$26
10% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$692	$1,028	$1,837	$878
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$979	$1,364	$2,293	$1,193
Battery discharge system	$13	$13	$13	$13
Total	$328	$1,111	$1,995	-$26
20% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$162	$152
High voltage wiring	$196	$201	$204	$200
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$692	$1,028	$1,837	$878
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$979	$1,364	$2,293	$1,193
Battery discharge system	$13	$13	$13	$13
Total	$328	$1,111	$1,995	-$26

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table 3-102 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV150 for the 2010 Baseline (2010$) [a]

System	Small car	Standard car	Large car	Small MPV
0% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164

Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$729	$1,094	$1,932	$946
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,021	$1,441	$2,402	$1,271
Battery discharge system	$13	$13	$13	$13
Total	$406	$1,255	$2,214	$132
2% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$720	$1,081	$1,910	$941
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,011	$1,425	$2,377	$1,265
Battery discharge system	$13	$13	$13	$13
Total	$387	$1,226	$2,167	$121
7.5% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$720	$1,081	$1,910	$941
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,011	$1,425	$2,377	$1,265
Battery discharge system	$13	$13	$13	$13
Total	$387	$1,226	$2,167	$121
10% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$720	$1,081	$1,910	$941
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394

Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,011	$1,425	$2,377	$1,265
Battery discharge system	$13	$13	$13	$13
Total	$387	$1,226	$2,167	$121
20% WR				
Brake system	$223	$229	$232	$225
Climate controls	$140	$157	$168	$164
Delete electrical	-$60	-$65	-$82	-$86
DC-DC converter	$121	$152	$177	$162
High voltage wiring	$197	$202	$205	$201
Supplemental heater	$76	$85	$91	$89
On vehicle charger	$316	$316	$316	$316
Motor inverter	$720	$1,081	$1,910	$941
Controls	$121	$121	$121	$121
Delete IC engine	-$1,596	-$1,596	-$2,466	-$2,394
Delete transmission	-$894	-$894	-$894	-$894
Motor assembly	$1,011	$1,425	$2,377	$1,265
Battery discharge system	$13	$13	$13	$13
Total	$387	$1,226	$2,167	$121

a The agencies have not estimated PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Similar to the approach taken for battery pack costs, the agencies generated linear regressions of non-battery system costs against percent of net mass reduction and the results are shown in Table 3-103. This was done using the same weight reduction offsets as used for battery packs as presented in Table 3-75. The agencies separated battery pack costs from the remainder of the systems for each type of electrified vehicle. The advantage of separating the battery pack costs from other system costs is that it allows each to carry unique indirect cost multipliers and learning effects which are important given that battery technology is an emerging technology, while electric motors and inverters are more stable technologies.

Table 3-103 Linear Regressions of Non-Battery System Direct Manufacturing Costs vs Net Mass reduction (2010$)

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
2008 Baseline						
Small car	-$263x+$1,675	-$1,316x+$2,878	-$1,316x+$2,878	-$1,510x+$350	-$1,510x+$350	-$1,510x+$351
Standard car	-$391x+$1,857	-$1,953x+$3,575	-$1,953x+$3,575	-$2,242x+$1,145	-$2,242x+$1,145	-$2,242x+$1,146
Large car	-$699x+$2,175	-$3,495x+$5,129	-$3,495x+$5,129	-$4,012x+$2,060	-$4,012x+$2,060	-$4,012x+$2,061
Small MPV	-$331x+$1,777	-$1,655x+$3,258	-$1,655x+$3,258	-$1,900x+-$12	-$1,900x+-$12	-$1,900x+-$11
Large MPV	-$506x+$2,052					
Truck	-$648x+$2,169					
2010 Baseline						
Small car	-$279x+$1,683	-$1,397x+$2,951	-$1,397x+$2,951	-$1,565x+$406	-$1,565x+$406	-$1,565x+$406
Standard car	-$420x+$1,878	-$2,099x+$3,712	-$2,099x+$3,712	-$2,350x+$1,255	-$2,350x+$1,255	-$2,350x+$1,255
Large car	-$741x+$2,224	-$3,705x+$5,347	-$3,705x+$5,347	-$4,149x+$2,214	-$4,149x+$2,214	-$4,149x+$2,214
Small MPV	-$363x+$1,811	-$1,814x+$3,419	-$1,814x+$3,419	-$2,032x+$132	-$2,032x+$132	-$2,032x+$132
Large MPV	-$528x+$2,073					
Truck	-$674x+$2,188					

Notes:

"x" in the equations represents the net weight reduction as a percentage, so the non-battery components for a small car P2 HEV (2008 baseline) with a 20% applied weight reduction and, therefore, a 15% net weight reduction would cost (-$263)x(15%)+$1,675=$1,635.The agencies did not regress PHEV or EV costs for the large MPV and truck vehicle classes since we do not believe these vehicle classes would use the technologies.

For P2 HEV and PHEV non-battery components, the direct manufacturing costs shown in Table 3-103 are considered applicable to the 2012MY. The agencies consider the P2 and PHEV non-battery component technologies to be on the flat portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a high1 complexity ICM of 1.56 through 2018 then 1.35 thereafter. For EV non-battery components, the direct manufacturing costs shown in Table 3-103 are considered applicable to the 2017MY. The agencies consider the EV non-battery component technologies to be on the flat portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a high2 complexity ICM of 1.77 through 2024 then 1.50 thereafter. The resultant costs for P2 HEV, PHEV20, PHEV40, EV75, EV100 and EV150 non-battery components for the 2008 and 2010 baselines are shown in Table 3-104 through Table 3-115, respectively.[aaa]

Table 3-104 Costs for P2 HEV Non-Battery Components for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	5%	$1,442	$1,413	$1,385	$1,357	$1,330	$1,303	$1,277	$1,252	$1,227
DMC	Small car	15%	10%	$1,430	$1,402	$1,374	$1,346	$1,319	$1,293	$1,267	$1,242	$1,217
DMC	Small car	20%	15%	$1,419	$1,391	$1,363	$1,335	$1,309	$1,283	$1,257	$1,232	$1,207
DMC	Standard car	10%	5%	$1,594	$1,562	$1,531	$1,500	$1,470	$1,441	$1,412	$1,384	$1,356
DMC	Standard car	15%	10%	$1,577	$1,546	$1,515	$1,484	$1,455	$1,426	$1,397	$1,369	$1,342
DMC	Standard car	20%	15%	$1,560	$1,529	$1,498	$1,468	$1,439	$1,410	$1,382	$1,354	$1,327
DMC	Large car	10%	5%	$1,857	$1,820	$1,783	$1,747	$1,713	$1,678	$1,645	$1,612	$1,580
DMC	Large car	15%	10%	$1,826	$1,790	$1,754	$1,719	$1,685	$1,651	$1,618	$1,585	$1,554
DMC	Large car	20%	15%	$1,796	$1,760	$1,725	$1,690	$1,657	$1,623	$1,591	$1,559	$1,528
DMC	Small MPV	10%	5%	$1,528	$1,497	$1,467	$1,438	$1,409	$1,381	$1,353	$1,326	$1,300
DMC	Small MPV	15%	10%	$1,513	$1,483	$1,453	$1,424	$1,396	$1,368	$1,340	$1,314	$1,287
DMC	Small MPV	20%	15%	$1,499	$1,469	$1,440	$1,411	$1,383	$1,355	$1,328	$1,301	$1,275
DMC	Large MPV	10%	5%	$1,759	$1,723	$1,689	$1,655	$1,622	$1,590	$1,558	$1,527	$1,496
DMC	Large MPV	15%	10%	$1,737	$1,702	$1,668	$1,634	$1,602	$1,570	$1,538	$1,508	$1,477
DMC	Large MPV	20%	15%	$1,715	$1,680	$1,647	$1,614	$1,582	$1,550	$1,519	$1,489	$1,459
DMC	Truck	10%	6%	$1,848	$1,811	$1,775	$1,739	$1,705	$1,670	$1,637	$1,604	$1,572
DMC	Truck	15%	11%	$1,820	$1,784	$1,748	$1,713	$1,679	$1,645	$1,612	$1,580	$1,548
DMC	Truck	20%	16%	$1,792	$1,756	$1,721	$1,686	$1,653	$1,620	$1,587	$1,556	$1,524
IC	Small car	10%	5%	$922	$920	$565	$564	$563	$563	$562	$561	$560

[aaa] Note that, in the draft Joint TSD, we inadvertently stated the following with respect to the years in which costs were considered valid and the years for which near term and long term ICMs were applied: "For P2 HEV non-battery components, the direct manufacturing costs shown in Table 3-103 are considered applicable to the 2017MY. The agencies consider the P2 non-battery component technologies to be on the flat portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a high1 complexity ICM of 1.56 through 2018 then 1.35 thereafter. For PHEV and EV non-battery components, the direct manufacturing costs shown in Table 3-103 are considered applicable to the 2025MY. The agencies consider the PHEV and EV non-battery component technologies to be on the flat portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a high2 complexity ICM of 1.77 through 2024 then 1.50 thereafter." Importantly, the costs then (and now) were calculated according to the corrected text shown in this final Joint TSD.

IC	Small car	15%	10%	$915	$913	$561	$560	$559	$558	$557	$556	$556
IC	Small car	20%	15%	$908	$906	$556	$555	$554	$554	$553	$552	$551
IC	Standard car	10%	5%	$1,020	$1,018	$625	$624	$623	$622	$621	$620	$619
IC	Standard car	15%	10%	$1,009	$1,007	$618	$617	$616	$615	$614	$614	$613
IC	Standard car	20%	15%	$998	$996	$612	$611	$610	$609	$608	$607	$606
IC	Large car	10%	5%	$1,188	$1,185	$728	$727	$726	$724	$723	$722	$721
IC	Large car	15%	10%	$1,168	$1,166	$716	$715	$714	$713	$712	$711	$710
IC	Large car	20%	15%	$1,149	$1,147	$704	$703	$702	$701	$700	$699	$698
IC	Small MPV	10%	5%	$977	$975	$599	$598	$597	$596	$595	$594	$593
IC	Small MPV	15%	10%	$968	$966	$593	$592	$591	$590	$590	$589	$588
IC	Small MPV	20%	15%	$959	$957	$588	$587	$586	$585	$584	$583	$582
IC	Large MPV	10%	5%	$1,125	$1,123	$689	$688	$687	$686	$685	$684	$683
IC	Large MPV	15%	10%	$1,111	$1,109	$681	$680	$679	$678	$677	$676	$675
IC	Large MPV	20%	15%	$1,097	$1,095	$672	$671	$670	$669	$668	$667	$666
IC	Truck	10%	6%	$1,182	$1,180	$724	$723	$722	$721	$720	$719	$718
IC	Truck	15%	11%	$1,164	$1,162	$713	$712	$711	$710	$709	$708	$707
IC	Truck	20%	16%	$1,146	$1,144	$702	$701	$700	$699	$698	$697	$696
TC	Small car	10%	5%	$2,364	$2,333	$1,950	$1,921	$1,893	$1,866	$1,839	$1,813	$1,787
TC	Small car	15%	10%	$2,345	$2,315	$1,934	$1,906	$1,878	$1,851	$1,824	$1,798	$1,773
TC	Small car	20%	15%	$2,327	$2,296	$1,919	$1,891	$1,863	$1,836	$1,810	$1,784	$1,758
TC	Standard car	10%	5%	$2,614	$2,580	$2,156	$2,124	$2,093	$2,063	$2,033	$2,004	$1,975
TC	Standard car	15%	10%	$2,586	$2,552	$2,133	$2,102	$2,071	$2,041	$2,012	$1,983	$1,954
TC	Standard car	20%	15%	$2,558	$2,525	$2,110	$2,079	$2,049	$2,019	$1,990	$1,961	$1,933
TC	Large car	10%	5%	$3,044	$3,005	$2,511	$2,474	$2,438	$2,403	$2,368	$2,334	$2,301
TC	Large car	15%	10%	$2,995	$2,956	$2,470	$2,434	$2,398	$2,364	$2,329	$2,296	$2,263
TC	Large car	20%	15%	$2,945	$2,907	$2,429	$2,393	$2,358	$2,324	$2,291	$2,258	$2,226
TC	Small MPV	10%	5%	$2,505	$2,472	$2,066	$2,036	$2,006	$1,977	$1,948	$1,920	$1,893
TC	Small MPV	15%	10%	$2,481	$2,449	$2,046	$2,016	$1,987	$1,958	$1,930	$1,902	$1,875
TC	Small MPV	20%	15%	$2,458	$2,426	$2,027	$1,997	$1,968	$1,940	$1,912	$1,884	$1,857
TC	Large MPV	10%	5%	$2,884	$2,846	$2,378	$2,343	$2,309	$2,276	$2,243	$2,211	$2,179
TC	Large MPV	15%	10%	$2,848	$2,811	$2,349	$2,314	$2,280	$2,247	$2,215	$2,183	$2,152
TC	Large MPV	20%	15%	$2,812	$2,775	$2,319	$2,285	$2,252	$2,219	$2,187	$2,156	$2,125
TC	Truck	10%	6%	$3,030	$2,991	$2,499	$2,463	$2,427	$2,392	$2,357	$2,323	$2,290
TC	Truck	15%	11%	$2,984	$2,946	$2,461	$2,425	$2,390	$2,355	$2,321	$2,288	$2,255
TC	Truck	20%	16%	$2,938	$2,900	$2,423	$2,388	$2,353	$2,319	$2,285	$2,253	$2,221

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-105 Costs for P2 HEV Non-Battery Components for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	5%	$1,448	$1,419	$1,390	$1,363	$1,335	$1,309	$1,282	$1,257	$1,232
DMC	Small car	15%	10%	$1,436	$1,407	$1,379	$1,351	$1,324	$1,298	$1,272	$1,246	$1,221
DMC	Small car	20%	15%	$1,423	$1,395	$1,367	$1,340	$1,313	$1,287	$1,261	$1,236	$1,211
DMC	Standard car	10%	5%	$1,611	$1,579	$1,547	$1,516	$1,486	$1,456	$1,427	$1,398	$1,370
DMC	Standard car	15%	10%	$1,593	$1,561	$1,529	$1,499	$1,469	$1,440	$1,411	$1,383	$1,355
DMC	Standard car	20%	15%	$1,574	$1,543	$1,512	$1,482	$1,452	$1,423	$1,395	$1,367	$1,339
DMC	Large car	10%	5%	$1,898	$1,860	$1,823	$1,786	$1,750	$1,715	$1,681	$1,647	$1,614
DMC	Large car	15%	10%	$1,866	$1,828	$1,792	$1,756	$1,721	$1,686	$1,653	$1,620	$1,587
DMC	Large car	20%	15%	$1,833	$1,797	$1,761	$1,726	$1,691	$1,657	$1,624	$1,592	$1,560
DMC	Small MPV	10%	5%	$1,555	$1,524	$1,494	$1,464	$1,435	$1,406	$1,378	$1,350	$1,323
DMC	Small MPV	15%	10%	$1,540	$1,509	$1,479	$1,449	$1,420	$1,392	$1,364	$1,337	$1,310
DMC	Small MPV	20%	15%	$1,524	$1,493	$1,464	$1,434	$1,406	$1,377	$1,350	$1,323	$1,296
DMC	Large MPV	10%	5%	$1,776	$1,740	$1,706	$1,672	$1,638	$1,605	$1,573	$1,542	$1,511
DMC	Large MPV	15%	10%	$1,753	$1,718	$1,684	$1,650	$1,617	$1,585	$1,553	$1,522	$1,491
DMC	Large MPV	20%	15%	$1,730	$1,696	$1,662	$1,628	$1,596	$1,564	$1,533	$1,502	$1,472
DMC	Truck	10%	6%	$1,863	$1,826	$1,790	$1,754	$1,719	$1,684	$1,651	$1,618	$1,585

DMC	Truck	15%	11%	$1,834	$1,798	$1,762	$1,726	$1,692	$1,658	$1,625	$1,592	$1,560
DMC	Truck	20%	16%	$1,805	$1,769	$1,733	$1,699	$1,665	$1,632	$1,599	$1,567	$1,536
IC	Small car	10%	5%	$926	$924	$568	$567	$566	$565	$564	$563	$562
IC	Small car	15%	10%	$918	$917	$563	$562	$561	$560	$559	$559	$558
IC	Small car	20%	15%	$911	$909	$558	$557	$556	$555	$555	$554	$553
IC	Standard car	10%	5%	$1,030	$1,028	$631	$630	$629	$629	$628	$627	$626
IC	Standard car	15%	10%	$1,019	$1,017	$624	$623	$622	$621	$620	$620	$619
IC	Standard car	20%	15%	$1,007	$1,005	$617	$616	$615	$614	$613	$613	$612
IC	Large car	10%	5%	$1,214	$1,212	$744	$743	$742	$740	$739	$738	$737
IC	Large car	15%	10%	$1,193	$1,191	$731	$730	$729	$728	$727	$726	$725
IC	Large car	20%	15%	$1,173	$1,171	$719	$718	$716	$715	$714	$713	$712
IC	Small MPV	10%	5%	$995	$993	$610	$609	$608	$607	$606	$605	$604
IC	Small MPV	15%	10%	$985	$983	$604	$603	$602	$601	$600	$599	$598
IC	Small MPV	20%	15%	$975	$973	$597	$596	$596	$595	$594	$593	$592
IC	Large MPV	10%	5%	$1,136	$1,134	$696	$695	$694	$693	$692	$691	$690
IC	Large MPV	15%	10%	$1,122	$1,119	$687	$686	$685	$684	$683	$682	$681
IC	Large MPV	20%	15%	$1,107	$1,105	$678	$677	$676	$675	$674	$673	$672
IC	Truck	10%	6%	$1,192	$1,190	$730	$729	$728	$727	$726	$725	$724
IC	Truck	15%	11%	$1,173	$1,171	$719	$718	$717	$716	$715	$714	$713
IC	Truck	20%	16%	$1,155	$1,152	$708	$706	$705	$704	$703	$702	$701
TC	Small car	10%	5%	$2,374	$2,343	$1,958	$1,929	$1,901	$1,874	$1,847	$1,820	$1,794
TC	Small car	15%	10%	$2,354	$2,323	$1,942	$1,913	$1,885	$1,858	$1,831	$1,805	$1,779
TC	Small car	20%	15%	$2,334	$2,304	$1,925	$1,897	$1,869	$1,842	$1,816	$1,790	$1,764
TC	Standard car	10%	5%	$2,641	$2,607	$2,178	$2,146	$2,115	$2,085	$2,054	$2,025	$1,996
TC	Standard car	15%	10%	$2,611	$2,577	$2,154	$2,122	$2,091	$2,061	$2,031	$2,002	$1,974
TC	Standard car	20%	15%	$2,582	$2,548	$2,129	$2,098	$2,067	$2,037	$2,008	$1,979	$1,951
TC	Large car	10%	5%	$3,112	$3,071	$2,566	$2,529	$2,492	$2,456	$2,420	$2,386	$2,352
TC	Large car	15%	10%	$3,059	$3,019	$2,523	$2,486	$2,450	$2,414	$2,379	$2,345	$2,312
TC	Large car	20%	15%	$3,006	$2,967	$2,479	$2,443	$2,408	$2,373	$2,338	$2,305	$2,272
TC	Small MPV	10%	5%	$2,550	$2,517	$2,103	$2,073	$2,042	$2,013	$1,984	$1,955	$1,927
TC	Small MPV	15%	10%	$2,525	$2,492	$2,082	$2,052	$2,022	$1,992	$1,964	$1,936	$1,908
TC	Small MPV	20%	15%	$2,499	$2,466	$2,061	$2,031	$2,001	$1,972	$1,944	$1,916	$1,888
TC	Large MPV	10%	5%	$2,912	$2,874	$2,402	$2,367	$2,332	$2,298	$2,265	$2,233	$2,201
TC	Large MPV	15%	10%	$2,875	$2,837	$2,371	$2,336	$2,302	$2,269	$2,236	$2,204	$2,173
TC	Large MPV	20%	15%	$2,837	$2,800	$2,340	$2,306	$2,272	$2,239	$2,207	$2,175	$2,144
TC	Truck	10%	6%	$3,056	$3,016	$2,520	$2,483	$2,447	$2,412	$2,377	$2,343	$2,309
TC	Truck	15%	11%	$3,008	$2,969	$2,481	$2,444	$2,409	$2,374	$2,339	$2,306	$2,273
TC	Truck	20%	16%	$2,960	$2,921	$2,441	$2,405	$2,370	$2,336	$2,302	$2,269	$2,237

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-106 Costs for PHEV20 Non-Battery Components for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	3%	$2,463	$2,414	$2,365	$2,318	$2,272	$2,226	$2,182	$2,138	$2,095
DMC	Small car	15%	8%	$2,406	$2,358	$2,311	$2,264	$2,219	$2,175	$2,131	$2,089	$2,047
DMC	Small car	20%	13%	$2,349	$2,302	$2,256	$2,211	$2,166	$2,123	$2,081	$2,039	$1,998
DMC	Standard car	10%	3%	$3,050	$2,989	$2,930	$2,871	$2,814	$2,757	$2,702	$2,648	$2,595
DMC	Standard car	15%	8%	$2,966	$2,906	$2,848	$2,791	$2,735	$2,681	$2,627	$2,575	$2,523
DMC	Standard car	20%	13%	$2,881	$2,823	$2,767	$2,712	$2,657	$2,604	$2,552	$2,501	$2,451
DMC	Large car	10%	2%	$4,389	$4,301	$4,215	$4,131	$4,049	$3,968	$3,888	$3,810	$3,734
DMC	Large car	15%	7%	$4,238	$4,153	$4,070	$3,988	$3,909	$3,831	$3,754	$3,679	$3,605
DMC	Large car	20%	12%	$4,086	$4,004	$3,924	$3,846	$3,769	$3,693	$3,620	$3,547	$3,476
DMC	Small MPV	10%	3%	$2,784	$2,728	$2,673	$2,620	$2,568	$2,516	$2,466	$2,417	$2,368

DMC	Small MPV	15%	8%	$2,712	$2,658	$2,604	$2,552	$2,501	$2,451	$2,402	$2,354	$2,307
DMC	Small MPV	20%	13%	$2,640	$2,587	$2,536	$2,485	$2,435	$2,386	$2,339	$2,292	$2,246
IC	Small car	10%	3%	$1,576	$1,572	$965	$964	$963	$961	$960	$958	$957
IC	Small car	15%	8%	$1,539	$1,536	$943	$942	$940	$939	$937	$936	$935
IC	Small car	20%	13%	$1,503	$1,500	$921	$919	$918	$917	$915	$914	$913
IC	Standard car	10%	3%	$1,951	$1,948	$1,196	$1,194	$1,192	$1,190	$1,189	$1,187	$1,185
IC	Standard car	15%	8%	$1,897	$1,893	$1,163	$1,161	$1,159	$1,157	$1,156	$1,154	$1,152
IC	Standard car	20%	13%	$1,843	$1,839	$1,129	$1,128	$1,126	$1,124	$1,123	$1,121	$1,119
IC	Large car	10%	2%	$2,808	$2,802	$1,721	$1,718	$1,715	$1,713	$1,710	$1,708	$1,705
IC	Large car	15%	7%	$2,711	$2,706	$1,661	$1,659	$1,656	$1,654	$1,651	$1,649	$1,646
IC	Large car	20%	12%	$2,614	$2,609	$1,602	$1,599	$1,597	$1,594	$1,592	$1,590	$1,587
IC	Small MPV	10%	3%	$1,781	$1,777	$1,091	$1,089	$1,088	$1,086	$1,085	$1,083	$1,081
IC	Small MPV	15%	8%	$1,735	$1,731	$1,063	$1,061	$1,060	$1,058	$1,057	$1,055	$1,054
IC	Small MPV	20%	13%	$1,689	$1,686	$1,035	$1,033	$1,032	$1,030	$1,029	$1,027	$1,026
TC	Small car	10%	3%	$4,039	$3,986	$3,331	$3,282	$3,234	$3,187	$3,141	$3,096	$3,052
TC	Small car	15%	8%	$3,945	$3,894	$3,254	$3,206	$3,159	$3,114	$3,069	$3,025	$2,982
TC	Small car	20%	13%	$3,851	$3,801	$3,177	$3,130	$3,084	$3,040	$2,996	$2,953	$2,911
TC	Standard car	10%	3%	$5,002	$4,937	$4,125	$4,065	$4,006	$3,948	$3,891	$3,835	$3,780
TC	Standard car	15%	8%	$4,863	$4,800	$4,011	$3,952	$3,894	$3,838	$3,783	$3,728	$3,675
TC	Standard car	20%	13%	$4,724	$4,663	$3,896	$3,839	$3,783	$3,728	$3,675	$3,622	$3,570
TC	Large car	10%	2%	$7,197	$7,104	$5,936	$5,849	$5,764	$5,680	$5,598	$5,518	$5,440
TC	Large car	15%	7%	$6,949	$6,858	$5,731	$5,647	$5,565	$5,484	$5,405	$5,328	$5,252
TC	Large car	20%	12%	$6,700	$6,613	$5,526	$5,445	$5,366	$5,288	$5,212	$5,137	$5,064
TC	Small MPV	10%	3%	$4,565	$4,505	$3,765	$3,709	$3,655	$3,602	$3,550	$3,500	$3,450
TC	Small MPV	15%	8%	$4,447	$4,389	$3,668	$3,614	$3,561	$3,510	$3,459	$3,409	$3,361
TC	Small MPV	20%	13%	$4,329	$4,273	$3,570	$3,518	$3,467	$3,417	$3,367	$3,319	$3,272

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-107 Costs for PHEV20 Non-Battery Components for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	3%	$2,524	$2,474	$2,424	$2,376	$2,328	$2,282	$2,236	$2,191	$2,148
DMC	Small car	15%	8%	$2,464	$2,414	$2,366	$2,319	$2,272	$2,227	$2,182	$2,139	$2,096
DMC	Small car	20%	13%	$2,403	$2,355	$2,308	$2,262	$2,217	$2,172	$2,129	$2,086	$2,044
DMC	Standard car	10%	3%	$3,166	$3,102	$3,040	$2,979	$2,920	$2,861	$2,804	$2,748	$2,693
DMC	Standard car	15%	8%	$3,075	$3,013	$2,953	$2,894	$2,836	$2,779	$2,724	$2,669	$2,616
DMC	Standard car	20%	13%	$2,984	$2,924	$2,865	$2,808	$2,752	$2,697	$2,643	$2,590	$2,538
DMC	Large car	10%	2%	$4,574	$4,483	$4,393	$4,305	$4,219	$4,135	$4,052	$3,971	$3,892
DMC	Large car	15%	7%	$4,414	$4,325	$4,239	$4,154	$4,071	$3,989	$3,910	$3,832	$3,755
DMC	Large car	20%	12%	$4,253	$4,168	$4,084	$4,003	$3,923	$3,844	$3,767	$3,692	$3,618
DMC	Small MPV	10%	3%	$2,919	$2,861	$2,804	$2,748	$2,693	$2,639	$2,586	$2,534	$2,484
DMC	Small MPV	15%	8%	$2,841	$2,784	$2,728	$2,674	$2,620	$2,568	$2,516	$2,466	$2,417
DMC	Small MPV	20%	13%	$2,762	$2,707	$2,653	$2,600	$2,548	$2,497	$2,447	$2,398	$2,350
IC	Small car	10%	3%	$1,615	$1,612	$990	$988	$986	$985	$984	$982	$981
IC	Small car	15%	8%	$1,576	$1,573	$966	$964	$963	$961	$960	$959	$957
IC	Small car	20%	13%	$1,537	$1,534	$942	$941	$939	$938	$936	$935	$934
IC	Standard car	10%	3%	$2,025	$2,021	$1,241	$1,239	$1,237	$1,235	$1,233	$1,232	$1,230
IC	Standard car	15%	8%	$1,967	$1,963	$1,205	$1,203	$1,202	$1,200	$1,198	$1,196	$1,195
IC	Standard car	20%	13%	$1,909	$1,905	$1,170	$1,168	$1,166	$1,164	$1,162	$1,161	$1,159
IC	Large car	10%	2%	$2,926	$2,920	$1,793	$1,790	$1,788	$1,785	$1,782	$1,780	$1,777
IC	Large car	15%	7%	$2,824	$2,818	$1,730	$1,727	$1,725	$1,722	$1,720	$1,717	$1,715
IC	Large car	20%	12%	$2,721	$2,715	$1,667	$1,664	$1,662	$1,659	$1,657	$1,655	$1,652
IC	Small MPV	10%	3%	$1,868	$1,864	$1,144	$1,143	$1,141	$1,139	$1,137	$1,136	$1,134
IC	Small MPV	15%	8%	$1,817	$1,814	$1,114	$1,112	$1,110	$1,108	$1,107	$1,105	$1,104
IC	Small MPV	20%	13%	$1,767	$1,763	$1,083	$1,081	$1,079	$1,078	$1,076	$1,075	$1,073
TC	Small car	10%	3%	$4,139	$4,085	$3,414	$3,364	$3,315	$3,267	$3,220	$3,174	$3,128

TC	Small car	15%	8%	$4,040	$3,987	$3,332	$3,283	$3,235	$3,188	$3,142	$3,097	$3,053
TC	Small car	20%	13%	$3,940	$3,889	$3,250	$3,202	$3,156	$3,110	$3,065	$3,021	$2,978
TC	Standard car	10%	3%	$5,191	$5,123	$4,281	$4,218	$4,157	$4,097	$4,038	$3,980	$3,923
TC	Standard car	15%	8%	$5,042	$4,976	$4,158	$4,097	$4,037	$3,979	$3,922	$3,865	$3,810
TC	Standard car	20%	13%	$4,892	$4,829	$4,035	$3,976	$3,918	$3,861	$3,805	$3,751	$3,697
TC	Large car	10%	2%	$7,501	$7,403	$6,186	$6,096	$6,007	$5,920	$5,834	$5,751	$5,669
TC	Large car	15%	7%	$7,237	$7,143	$5,969	$5,881	$5,796	$5,712	$5,629	$5,549	$5,470
TC	Large car	20%	12%	$6,974	$6,883	$5,752	$5,667	$5,585	$5,504	$5,424	$5,347	$5,270
TC	Small MPV	10%	3%	$4,787	$4,725	$3,948	$3,890	$3,834	$3,778	$3,724	$3,670	$3,618
TC	Small MPV	15%	8%	$4,658	$4,597	$3,842	$3,785	$3,730	$3,676	$3,623	$3,571	$3,520
TC	Small MPV	20%	13%	$4,529	$4,470	$3,735	$3,681	$3,627	$3,574	$3,523	$3,472	$3,423

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-108 Costs for PHEV40 Non-Battery Components for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	15%	2%	$2,474	$2,425	$2,376	$2,329	$2,282	$2,237	$2,192	$2,148	$2,105
DMC	Small car	20%	7%	$2,417	$2,369	$2,322	$2,275	$2,230	$2,185	$2,141	$2,099	$2,057
DMC	Std car	15%	3%	$3,050	$2,989	$2,930	$2,871	$2,814	$2,757	$2,702	$2,648	$2,595
DMC	Std car	20%	8%	$2,966	$2,906	$2,848	$2,791	$2,735	$2,681	$2,627	$2,575	$2,523
DMC	Large car	15%	1%	$4,420	$4,331	$4,245	$4,160	$4,076	$3,995	$3,915	$3,837	$3,760
DMC	Large car	20%	6%	$4,268	$4,183	$4,099	$4,017	$3,937	$3,858	$3,781	$3,705	$3,631
DMC	Small MPV	15%	3%	$2,784	$2,728	$2,673	$2,620	$2,568	$2,516	$2,466	$2,417	$2,368
DMC	Small MPV	20%	8%	$2,712	$2,658	$2,604	$2,552	$2,501	$2,451	$2,402	$2,354	$2,307
IC	Small car	15%	2%	$1,583	$1,580	$970	$968	$967	$966	$964	$963	$961
IC	Small car	20%	7%	$1,546	$1,543	$948	$946	$945	$943	$942	$940	$939
IC	Std car	15%	3%	$1,951	$1,948	$1,196	$1,194	$1,192	$1,190	$1,189	$1,187	$1,185
IC	Std car	20%	8%	$1,897	$1,893	$1,163	$1,161	$1,159	$1,157	$1,156	$1,154	$1,152
IC	Large car	15%	1%	$2,827	$2,822	$1,732	$1,730	$1,727	$1,725	$1,722	$1,719	$1,717
IC	Large car	20%	6%	$2,730	$2,725	$1,673	$1,670	$1,668	$1,665	$1,663	$1,661	$1,658
IC	Small MPV	15%	3%	$1,781	$1,777	$1,091	$1,089	$1,088	$1,086	$1,085	$1,083	$1,081
IC	Small MPV	20%	8%	$1,735	$1,731	$1,063	$1,061	$1,060	$1,058	$1,057	$1,055	$1,054
TC	Small car	15%	2%	$4,057	$4,005	$3,346	$3,297	$3,249	$3,202	$3,156	$3,111	$3,066
TC	Small car	20%	7%	$3,964	$3,912	$3,269	$3,221	$3,174	$3,128	$3,083	$3,039	$2,996
TC	Std car	15%	3%	$5,002	$4,937	$4,125	$4,065	$4,006	$3,948	$3,891	$3,835	$3,780
TC	Std car	20%	8%	$4,863	$4,800	$4,011	$3,952	$3,894	$3,838	$3,783	$3,728	$3,675
TC	Large car	15%	1%	$7,247	$7,153	$5,977	$5,889	$5,804	$5,719	$5,637	$5,556	$5,477
TC	Large car	20%	6%	$6,998	$6,907	$5,772	$5,687	$5,605	$5,523	$5,444	$5,366	$5,289
TC	Small MPV	15%	3%	$4,565	$4,505	$3,765	$3,709	$3,655	$3,602	$3,550	$3,500	$3,450
TC	Small MPV	20%	8%	$4,447	$4,389	$3,668	$3,614	$3,561	$3,510	$3,459	$3,409	$3,361

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-109 Costs for PHEV40 Non-Battery Components for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	15%	3%	$2,524	$2,474	$2,424	$2,376	$2,328	$2,282	$2,236	$2,191	$2,148
DMC	Small car	20%	8%	$2,464	$2,414	$2,366	$2,319	$2,272	$2,227	$2,182	$2,139	$2,096
DMC	Std car	15%	3%	$3,166	$3,102	$3,040	$2,979	$2,920	$2,861	$2,804	$2,748	$2,693
DMC	Std car	20%	8%	$3,075	$3,013	$2,953	$2,894	$2,836	$2,779	$2,724	$2,669	$2,616
DMC	Large car	15%	2%	$4,574	$4,483	$4,393	$4,305	$4,219	$4,135	$4,052	$3,971	$3,892
DMC	Large car	20%	7%	$4,414	$4,325	$4,239	$4,154	$4,071	$3,989	$3,910	$3,832	$3,755
DMC	Small MPV	15%	3%	$2,919	$2,861	$2,804	$2,748	$2,693	$2,639	$2,586	$2,534	$2,484
DMC	Small MPV	20%	8%	$2,841	$2,784	$2,728	$2,674	$2,620	$2,568	$2,516	$2,466	$2,417

IC	Small car	15%	3%	$1,615	$1,612	$990	$988	$986	$985	$984	$982	$981
IC	Small car	20%	8%	$1,576	$1,573	$966	$964	$963	$961	$960	$959	$957
IC	Std car	15%	3%	$2,025	$2,021	$1,241	$1,239	$1,237	$1,235	$1,233	$1,232	$1,230
IC	Std car	20%	8%	$1,967	$1,963	$1,205	$1,203	$1,202	$1,200	$1,198	$1,196	$1,195
IC	Large car	15%	2%	$2,926	$2,920	$1,793	$1,790	$1,788	$1,785	$1,782	$1,780	$1,777
IC	Large car	20%	7%	$2,824	$2,818	$1,730	$1,727	$1,725	$1,722	$1,720	$1,717	$1,715
IC	Small MPV	15%	3%	$1,868	$1,864	$1,144	$1,143	$1,141	$1,139	$1,137	$1,136	$1,134
IC	Small MPV	20%	8%	$1,817	$1,814	$1,114	$1,112	$1,110	$1,108	$1,107	$1,105	$1,104
TC	Small car	15%	3%	$4,139	$4,085	$3,414	$3,364	$3,315	$3,267	$3,220	$3,174	$3,128
TC	Small car	20%	8%	$4,040	$3,987	$3,332	$3,283	$3,235	$3,188	$3,142	$3,097	$3,053
TC	Std car	15%	3%	$5,191	$5,123	$4,281	$4,218	$4,157	$4,097	$4,038	$3,980	$3,923
TC	Std car	20%	8%	$5,042	$4,976	$4,158	$4,097	$4,037	$3,979	$3,922	$3,865	$3,810
TC	Large car	15%	2%	$7,501	$7,403	$6,186	$6,096	$6,007	$5,920	$5,834	$5,751	$5,669
TC	Large car	20%	7%	$7,237	$7,143	$5,969	$5,881	$5,796	$5,712	$5,629	$5,549	$5,470
TC	Small MPV	15%	3%	$4,787	$4,725	$3,948	$3,890	$3,834	$3,778	$3,724	$3,670	$3,618
TC	Small MPV	20%	8%	$4,658	$4,597	$3,842	$3,785	$3,730	$3,676	$3,623	$3,571	$3,520

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-110 Costs for EV75 Non-Battery Components for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	10%	$199	$193	$187	$182	$176	$171	$168	$164	$161
DMC	Small car	15%	15%	$124	$120	$116	$113	$109	$106	$104	$102	$100
DMC	Small car	20%	20%	$48	$47	$45	$44	$43	$41	$40	$40	$39
DMC	Std car	10%	10%	$921	$893	$866	$840	$815	$791	$775	$759	$744
DMC	Std car	15%	15%	$809	$784	$761	$738	$716	$694	$681	$667	$654
DMC	Std car	20%	20%	$697	$676	$655	$636	$617	$598	$586	$574	$563
DMC	Large car	10%	10%	$1,659	$1,609	$1,560	$1,514	$1,468	$1,424	$1,396	$1,368	$1,340
DMC	Large car	15%	15%	$1,458	$1,414	$1,372	$1,331	$1,291	$1,252	$1,227	$1,202	$1,178
DMC	Large car	20%	20%	$1,257	$1,220	$1,183	$1,148	$1,113	$1,080	$1,058	$1,037	$1,016
DMC	Small MPV	10%	9%	-$183	-$177	-$172	-$167	-$162	-$157	-$154	-$151	-$148
DMC	Small MPV	15%	14%	-$278	-$269	-$261	-$254	-$246	-$239	-$234	-$229	-$225
DMC	Small MPV	20%	19%	-$373	-$362	-$351	-$340	-$330	-$320	-$314	-$307	-$301
IC	Small car	10%	10%	$153	$153	$152	$152	$152	$151	$151	$151	$97
IC	Small car	15%	15%	$95	$95	$95	$94	$94	$94	$94	$94	$60
IC	Small car	20%	20%	$37	$37	$37	$37	$37	$37	$36	$36	$23
IC	Std car	10%	10%	$709	$707	$705	$703	$701	$699	$698	$697	$449
IC	Std car	15%	15%	$623	$621	$619	$618	$616	$614	$613	$612	$394
IC	Std car	20%	20%	$536	$535	$533	$532	$531	$529	$528	$527	$339
IC	Large car	10%	10%	$1,277	$1,273	$1,270	$1,266	$1,263	$1,260	$1,258	$1,256	$808
IC	Large car	15%	15%	$1,123	$1,119	$1,116	$1,113	$1,110	$1,107	$1,106	$1,104	$710
IC	Large car	20%	20%	$968	$965	$963	$960	$958	$955	$954	$952	$613
IC	Small MPV	10%	9%	-$141	-$140	-$140	-$140	-$139	-$139	-$139	-$138	-$89
IC	Small MPV	15%	14%	-$214	-$213	-$213	-$212	-$212	-$211	-$211	-$210	-$135
IC	Small MPV	20%	19%	-$287	-$286	-$285	-$285	-$284	-$283	-$283	-$282	-$182
TC	Small car	10%	10%	$352	$346	$340	$334	$328	$322	$319	$315	$258
TC	Small car	15%	15%	$219	$215	$211	$207	$204	$200	$198	$195	$160
TC	Small car	20%	20%	$85	$84	$82	$81	$79	$78	$77	$76	$62
TC	Std car	10%	10%	$1,630	$1,600	$1,571	$1,543	$1,516	$1,490	$1,473	$1,457	$1,193
TC	Std car	15%	15%	$1,431	$1,405	$1,380	$1,356	$1,332	$1,309	$1,294	$1,279	$1,048
TC	Std car	20%	20%	$1,233	$1,211	$1,189	$1,168	$1,147	$1,127	$1,114	$1,102	$902
TC	Large car	10%	10%	$2,936	$2,882	$2,830	$2,780	$2,731	$2,684	$2,654	$2,624	$2,149
TC	Large car	15%	15%	$2,581	$2,534	$2,488	$2,444	$2,401	$2,359	$2,333	$2,306	$1,889
TC	Large car	20%	20%	$2,226	$2,185	$2,146	$2,108	$2,071	$2,035	$2,012	$1,989	$1,629
TC	Small MPV	10%	9%	-$324	-$318	-$312	-$306	-$301	-$296	-$293	-$289	-$237
TC	Small MPV	15%	14%	-$492	-$483	-$474	-$466	-$458	-$450	-$444	-$439	-$360

TC	Small MPV	20%	19%	-$660	-$648	-$636	-$625	-$614	-$603	-$596	-$590	-$483

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-111 Costs for EV75 Non-Battery Components for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	10%	$250	$242	$235	$228	$221	$215	$210	$206	$202
DMC	Small car	15%	15%	$172	$166	$161	$157	$152	$147	$144	$142	$139
DMC	Small car	20%	20%	$93	$91	$88	$85	$83	$80	$79	$77	$75
DMC	Std car	10%	9%	$1,043	$1,012	$982	$952	$924	$896	$878	$861	$843
DMC	Std car	15%	14%	$926	$898	$871	$845	$820	$795	$779	$764	$748
DMC	Std car	20%	19%	$808	$784	$761	$738	$716	$694	$680	$667	$653
DMC	Large car	10%	10%	$1,799	$1,745	$1,693	$1,642	$1,593	$1,545	$1,514	$1,484	$1,454
DMC	Large car	15%	15%	$1,592	$1,544	$1,498	$1,453	$1,409	$1,367	$1,340	$1,313	$1,287
DMC	Large car	20%	20%	$1,385	$1,343	$1,303	$1,264	$1,226	$1,189	$1,165	$1,142	$1,119
DMC	Small MPV	10%	9%	-$51	-$49	-$48	-$46	-$45	-$44	-$43	-$42	-$41
DMC	Small MPV	15%	14%	-$152	-$148	-$143	-$139	-$135	-$131	-$128	-$126	-$123
DMC	Small MPV	20%	19%	-$254	-$246	-$239	-$232	-$225	-$218	-$214	-$209	-$205
IC	Small car	10%	10%	$192	$192	$191	$191	$190	$190	$189	$189	$122
IC	Small car	15%	15%	$132	$132	$131	$131	$131	$130	$130	$130	$84
IC	Small car	20%	20%	$72	$72	$72	$71	$71	$71	$71	$71	$46
IC	Std car	10%	9%	$803	$801	$799	$797	$795	$793	$791	$790	$508
IC	Std car	15%	14%	$713	$711	$709	$707	$705	$703	$702	$701	$451
IC	Std car	20%	19%	$623	$621	$619	$617	$616	$614	$613	$612	$394
IC	Large car	10%	10%	$1,386	$1,382	$1,378	$1,374	$1,370	$1,367	$1,365	$1,362	$877
IC	Large car	15%	15%	$1,226	$1,222	$1,219	$1,216	$1,212	$1,209	$1,207	$1,205	$776
IC	Large car	20%	20%	$1,066	$1,063	$1,060	$1,057	$1,054	$1,052	$1,050	$1,048	$675
IC	Small MPV	10%	9%	-$39	-$39	-$39	-$39	-$39	-$38	-$38	-$38	-$25
IC	Small MPV	15%	14%	-$117	-$117	-$117	-$116	-$116	-$116	-$115	-$115	-$74
IC	Small MPV	20%	19%	-$195	-$195	-$194	-$194	-$193	-$193	-$193	-$192	-$124
TC	Small car	10%	10%	$442	$434	$426	$419	$412	$404	$400	$395	$324
TC	Small car	15%	15%	$304	$298	$293	$288	$283	$278	$275	$271	$222
TC	Small car	20%	20%	$165	$162	$159	$157	$154	$151	$149	$148	$121
TC	Std car	10%	9%	$1,847	$1,813	$1,781	$1,749	$1,718	$1,689	$1,669	$1,651	$1,352
TC	Std car	15%	14%	$1,639	$1,609	$1,580	$1,552	$1,525	$1,498	$1,481	$1,465	$1,199
TC	Std car	20%	19%	$1,431	$1,405	$1,380	$1,355	$1,331	$1,308	$1,293	$1,279	$1,047
TC	Large car	10%	10%	$3,185	$3,127	$3,071	$3,016	$2,963	$2,912	$2,879	$2,846	$2,331
TC	Large car	15%	15%	$2,818	$2,767	$2,717	$2,669	$2,622	$2,576	$2,547	$2,518	$2,062
TC	Large car	20%	20%	$2,451	$2,406	$2,363	$2,321	$2,280	$2,241	$2,215	$2,190	$1,794
TC	Small MPV	10%	9%	-$90	-$88	-$86	-$85	-$83	-$82	-$81	-$80	-$66
TC	Small MPV	15%	14%	-$270	-$265	-$260	-$255	-$251	-$246	-$244	-$241	-$197
TC	Small MPV	20%	19%	-$449	-$441	-$433	-$426	-$418	-$411	-$406	-$402	-$329

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-112 Costs for EV100 Non-Battery Components for the 2008 Baseline (2010$)

Cost type	EPA Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	4%	$290	$281	$273	$264	$256	$249	$244	$239	$234
DMC	Small car	15%	9%	$214	$208	$202	$195	$190	$184	$180	$177	$173
DMC	Small car	20%	14%	$139	$135	$130	$127	$123	$119	$117	$114	$112
DMC	Std car	10%	4%	$1,055	$1,024	$993	$963	$934	$906	$888	$870	$853
DMC	Std car	15%	9%	$943	$915	$887	$861	$835	$810	$794	$778	$762

DMC	Std car	20%	14%	$831	$806	$782	$759	$736	$714	$699	$685	$672
DMC	Large car	10%	5%	$1,859	$1,803	$1,749	$1,697	$1,646	$1,596	$1,565	$1,533	$1,503
DMC	Large car	15%	10%	$1,659	$1,609	$1,560	$1,514	$1,468	$1,424	$1,396	$1,368	$1,340
DMC	Large car	20%	15%	$1,458	$1,414	$1,372	$1,331	$1,291	$1,252	$1,227	$1,202	$1,178
DMC	Small MPV	10%	3%	-$69	-$67	-$65	-$63	-$61	-$59	-$58	-$57	-$56
DMC	Small MPV	15%	8%	-$164	-$159	-$154	-$150	-$145	-$141	-$138	-$135	-$132
DMC	Small MPV	20%	13%	-$259	-$251	-$244	-$236	-$229	-$222	-$218	-$213	-$209
IC	Small car	10%	4%	$223	$222	$222	$221	$221	$220	$220	$219	$141
IC	Small car	15%	9%	$165	$164	$164	$164	$163	$163	$162	$162	$104
IC	Small car	20%	14%	$107	$106	$106	$106	$106	$105	$105	$105	$68
IC	Std car	10%	4%	$813	$810	$808	$806	$804	$802	$800	$799	$514
IC	Std car	15%	9%	$726	$724	$722	$720	$718	$716	$715	$714	$460
IC	Std car	20%	14%	$640	$638	$636	$635	$633	$631	$630	$629	$405
IC	Large car	10%	5%	$1,432	$1,427	$1,423	$1,420	$1,416	$1,412	$1,410	$1,408	$906
IC	Large car	15%	10%	$1,277	$1,273	$1,270	$1,266	$1,263	$1,260	$1,258	$1,256	$808
IC	Large car	20%	15%	$1,123	$1,119	$1,116	$1,113	$1,110	$1,107	$1,106	$1,104	$710
IC	Small MPV	10%	3%	-$53	-$53	-$53	-$53	-$52	-$52	-$52	-$52	-$34
IC	Small MPV	15%	8%	-$126	-$126	-$125	-$125	-$125	-$124	-$124	-$124	-$80
IC	Small MPV	20%	13%	-$199	-$199	-$198	-$198	-$197	-$197	-$196	-$196	-$126
TC	Small car	10%	4%	$513	$503	$494	$486	$477	$469	$464	$458	$375
TC	Small car	15%	9%	$379	$372	$366	$359	$353	$347	$343	$339	$277
TC	Small car	20%	14%	$245	$241	$237	$232	$228	$224	$222	$219	$180
TC	Std car	10%	4%	$1,868	$1,834	$1,801	$1,769	$1,738	$1,708	$1,688	$1,669	$1,367
TC	Std car	15%	9%	$1,669	$1,639	$1,610	$1,581	$1,553	$1,526	$1,509	$1,492	$1,222
TC	Std car	20%	14%	$1,471	$1,444	$1,418	$1,393	$1,369	$1,345	$1,330	$1,315	$1,077
TC	Large car	10%	5%	$3,291	$3,231	$3,173	$3,116	$3,062	$3,009	$2,974	$2,941	$2,408
TC	Large car	15%	10%	$2,936	$2,882	$2,830	$2,780	$2,731	$2,684	$2,654	$2,624	$2,149
TC	Large car	20%	15%	$2,581	$2,534	$2,488	$2,444	$2,401	$2,359	$2,333	$2,306	$1,889
TC	Small MPV	10%	3%	-$122	-$120	-$117	-$115	-$113	-$111	-$110	-$109	-$89
TC	Small MPV	15%	8%	-$290	-$285	-$280	-$275	-$270	-$265	-$262	-$259	-$212
TC	Small MPV	20%	13%	-$458	-$450	-$442	-$434	-$426	-$419	-$414	-$409	-$335

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-113 Costs for EV100 Non-Battery Components for the 2010 Baseline (2010$)

Cost type	EPA Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	10%	4%	$344	$333	$323	$314	$304	$295	$289	$284	$278
DMC	Small car	15%	9%	$266	$258	$250	$242	$235	$228	$223	$219	$215
DMC	Small car	20%	14%	$187	$182	$176	$171	$166	$161	$158	$154	$151
DMC	Std car	10%	3%	$1,184	$1,149	$1,114	$1,081	$1,049	$1,017	$997	$977	$957
DMC	Std car	15%	8%	$1,067	$1,035	$1,004	$974	$945	$916	$898	$880	$862
DMC	Std car	20%	13%	$949	$921	$893	$866	$841	$815	$799	$783	$767
DMC	Large car	10%	4%	$2,048	$1,987	$1,927	$1,869	$1,813	$1,759	$1,724	$1,689	$1,656
DMC	Large car	15%	9%	$1,841	$1,786	$1,732	$1,680	$1,630	$1,581	$1,549	$1,518	$1,488
DMC	Large car	20%	14%	$1,633	$1,584	$1,537	$1,491	$1,446	$1,403	$1,375	$1,347	$1,320
DMC	Small MPV	10%	3%	$71	$69	$67	$65	$63	$61	$60	$59	$58
DMC	Small MPV	15%	8%	-$30	-$29	-$29	-$28	-$27	-$26	-$26	-$25	-$25
DMC	Small MPV	20%	13%	-$132	-$128	-$124	-$120	-$117	-$113	-$111	-$109	-$107
IC	Small car	10%	4%	$265	$264	$263	$262	$262	$261	$261	$260	$167
IC	Small car	15%	9%	$204	$204	$203	$203	$202	$202	$201	$201	$129
IC	Small car	20%	14%	$144	$144	$143	$143	$143	$142	$142	$142	$91
IC	Std car	10%	3%	$912	$909	$907	$904	$902	$900	$898	$897	$577
IC	Std car	15%	8%	$822	$819	$817	$815	$813	$810	$809	$808	$520
IC	Std car	20%	13%	$731	$729	$727	$725	$723	$721	$720	$719	$463
IC	Large car	10%	4%	$1,577	$1,573	$1,568	$1,564	$1,560	$1,556	$1,553	$1,551	$998

IC	Large car	15%	9%	$1,418	$1,413	$1,410	$1,406	$1,402	$1,398	$1,396	$1,394	$897
IC	Large car	20%	14%	$1,258	$1,254	$1,251	$1,247	$1,244	$1,241	$1,239	$1,237	$796
IC	Small MPV	10%	3%	$55	$55	$55	$54	$54	$54	$54	$54	$35
IC	Small MPV	15%	8%	-$23	-$23	-$23	-$23	-$23	-$23	-$23	-$23	-$15
IC	Small MPV	20%	13%	-$102	-$101	-$101	-$101	-$100	-$100	-$100	-$100	-$64
TC	Small car	10%	4%	$608	$597	$587	$576	$566	$556	$550	$544	$445
TC	Small car	15%	9%	$470	$461	$453	$445	$437	$430	$425	$420	$344
TC	Small car	20%	14%	$331	$325	$320	$314	$308	$303	$300	$296	$243
TC	Std car	10%	3%	$2,096	$2,058	$2,021	$1,985	$1,951	$1,917	$1,895	$1,874	$1,534
TC	Std car	15%	8%	$1,888	$1,854	$1,821	$1,788	$1,757	$1,727	$1,707	$1,688	$1,382
TC	Std car	20%	13%	$1,680	$1,650	$1,620	$1,591	$1,564	$1,536	$1,519	$1,502	$1,230
TC	Large car	10%	4%	$3,626	$3,560	$3,496	$3,434	$3,373	$3,315	$3,277	$3,240	$2,654
TC	Large car	15%	9%	$3,258	$3,199	$3,142	$3,086	$3,032	$2,979	$2,945	$2,912	$2,385
TC	Large car	20%	14%	$2,891	$2,839	$2,788	$2,738	$2,690	$2,644	$2,613	$2,584	$2,116
TC	Small MPV	10%	3%	$126	$124	$122	$119	$117	$115	$114	$113	$92
TC	Small MPV	15%	8%	-$54	-$53	-$52	-$51	-$50	-$49	-$49	-$48	-$39
TC	Small MPV	20%	13%	-$234	-$229	-$225	-$221	-$217	-$214	-$211	-$209	-$171

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-114 Costs for EV150 Non-Battery Components for the 2008 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	20%	2%	$321	$312	$302	$293	$284	$276	$270	$265	$260
DMC	Std car	20%	2%	$1,101	$1,068	$1,036	$1,005	$975	$945	$927	$908	$890
DMC	Large car	20%	3%	$1,941	$1,882	$1,826	$1,771	$1,718	$1,667	$1,633	$1,601	$1,569
DMC	Small MPV	20%	1%	-$30	-$29	-$29	-$28	-$27	-$26	-$26	-$25	-$25
IC	Small car	20%	2%	$247	$247	$246	$245	$245	$244	$244	$243	$157
IC	Std car	20%	2%	$848	$845	$843	$841	$838	$836	$835	$834	$536
IC	Large car	20%	3%	$1,494	$1,490	$1,486	$1,482	$1,478	$1,474	$1,472	$1,469	$946
IC	Small MPV	20%	1%	-$23	-$23	-$23	-$23	-$23	-$23	-$23	-$23	-$15
TC	Small car	20%	2%	$569	$558	$548	$538	$529	$520	$514	$508	$416
TC	Std car	20%	2%	$1,949	$1,913	$1,879	$1,846	$1,813	$1,782	$1,761	$1,742	$1,426
TC	Large car	20%	3%	$3,435	$3,373	$3,312	$3,253	$3,196	$3,141	$3,105	$3,070	$2,514
TC	Small MPV	20%	1%	-$54	-$53	-$52	-$51	-$50	-$49	-$49	-$48	-$39

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 3-115 Costs for EV150 Non-Battery Components for the 2010 Baseline (2010$)

Cost type	Vehicle class	Applied WR	Net WR	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Small car	20%	1%	$391	$379	$368	$357	$346	$336	$329	$322	$316
DMC	Std car	20%	1%	$1,231	$1,194	$1,159	$1,124	$1,090	$1,057	$1,036	$1,016	$995
DMC	Large car	20%	3%	$2,090	$2,027	$1,966	$1,907	$1,850	$1,795	$1,759	$1,724	$1,689
DMC	Small MPV	20%	1%	$112	$108	$105	$102	$99	$96	$94	$92	$90
IC	Small car	20%	1%	$301	$300	$299	$298	$298	$297	$296	$296	$190
IC	Std car	20%	1%	$948	$945	$943	$940	$938	$935	$934	$932	$600
IC	Large car	20%	3%	$1,609	$1,605	$1,600	$1,596	$1,592	$1,587	$1,585	$1,582	$1,018
IC	Small MPV	20%	1%	$86	$86	$86	$85	$85	$85	$85	$85	$54
TC	Small car	20%	1%	$692	$679	$667	$655	$643	$632	$625	$618	$506
TC	Std car	20%	1%	$2,180	$2,140	$2,101	$2,064	$2,028	$1,993	$1,970	$1,948	$1,595
TC	Large car	20%	3%	$3,699	$3,632	$3,566	$3,503	$3,442	$3,382	$3,344	$3,306	$2,707
TC	Small MPV	20%	1%	$198	$194	$191	$187	$184	$181	$179	$177	$145

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

For Mild HEV non-battery components, the agencies have used a combination of cost sources which include the FEV teardown of a Saturn Vue along with estimates used for P2

HEVs as described above. For the electrical power distribution and control system and the DC-DC converter, estimates presented in the NPRM for subcompacts were used with a presumed 20% weight reduction because those systems were estimated to include a 16 kW motor (essentially the same as the 15 kW motor assumed for the Mild HEV technology). These costs and the FEV Saturn Vue teardown costs we used are shown in Table 3-116.

Table 3-116 FEV Teardown Results & P2 HEV Values used for MHEV Non-Battery Direct Manufacturing Cost Estimates

System	Teardown result (2007$)	P2 HEV (2009$)[a]	2010$
Cooling subsystem (including water pumps)	$88.71		$92.37
Accessory drive subsystem	$30.75		$32.02
Body system	$14.83		$15.44
Brake system	$42.30		$44.05
Climate control system	$0		$0
Transmission oil pump and filter subsystem	$53.86		$56.09
Generator/alternator and regulatory subsystem	$51.94		$54.09
Electrical power distribution & control system		$203.22	$205.25
DC-DC converter		$115.33	$116.48
Total			$615.79
[a] See the draft Joint TSD, Table 3-80, 20% WR (EPA-420-D-11-901, November 2011).			

For Mild HEV non-battery components, the direct manufacturing costs shown in Table 3-116 are considered applicable MY 2012. The agencies consider the Mild HEV non-battery component technologies to be on the flat portion of the learning curve during the 2017-2025 timeframe. The agencies have applied a medium complexity ICM of 1.39 through 2018 then 1.29 thereafter. The resultant costs used in this final analysis are shown in Table 3-117.

Table 3-117 Costs for Mild HEV Non-Battery Components for both the 2008 and 2010 Baselines (2010$)

Cost type	Vehicle class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	$534	$524	$513	$503	$493	$483	$473	$464	$455
IC	All	$235	$234	$175	$175	$175	$174	$174	$174	$173
TC	All	$769	$758	$688	$678	$667	$657	$647	$637	$628

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.4 Hardware costs for charging grid-connected vehicles

Grid-connected vehicles such as EVs and PHEVs require a means to charge their on-board batteries to enable their electric range capabilities. These vehicles require certain hardware to charge, both on-vehicle and off-vehicle. The agencies' September 2010 Technical

Assessment Report contains an in-depth analysis of the topic of charging and infrastructure. The TAR analysis and assumptions did not receive any significant comment, and a review of the current state of the industry indicates the assumptions in the TAR are still valid. Therefore, the assumptions for the cost of Electric Vehicle Support Equipment (EVSE) are unchanged. Additionally, while some of the characteristics of the modeled grid-connected vehicles such as battery size and energy demand have changed somewhat due to further analysis, the application of Level 1 and Level 2 charging by vehicle type based on charge time has not changed.

Three charging levels are currently under consideration. Level 1 charging uses a standard 120 volt (V), 15-20 amps (A) rated (12-16 A usable) circuit and is available in standard residential and commercial buildings. Level 2 charging uses a single phase, 240 V, 20-80 A circuit and allows much shorter charge times. Level 3 charging—sometimes colloquially called "quick" or "fast" charging—uses a 480 V, three-phase circuit, available in mainly industrial areas, typically providing 60-150 kW of off-board charging power. It is expected that 97 to 99% of charging will take place at home, so a cost for a home charger, appropriate to the duty cycle of the vehicle, is added to the vehicle cost. Level 3 charging is available to commercial users and vehicles that charge at Level 3 stations will be assumed to pay at the charge station for the convenience of fast charging. Therefore Level 3 charger costs are not included in overall vehicle cost.

The specific equipment required for charging a grid-connected vehicle consists of the following:

Charger: A charger that converts electricity from alternating current (AC) from the electricity source to direct current (DC) required for the battery, and also converts the incoming 120 or 240 volt current to 300 or higher volts. Grid-connected vehicles carry an on-board charger capable of accepting AC current from a wall plug (Level 1 circuit) or, from a Level 2 charging station. On-board charger power capability ranges from 1.4 to 10 kW and is usually proportional to the vehicle's battery capacity. The lowest charging power, 1.4 kW, is expected only when grid-connected vehicles are connected to 120 volt (Level 1) outlets, and all currently known PHEV and EV on-board chargers are expected to provide at least 3.3 kW charging when connected to a Level 2 (220 volt, 20+ A) charging station. The latest SAE connection recommended practice, J1772, allows for delivery of up to ~19 kW to an on-board vehicle charger. For higher capacity charging under Level 3, a charging station that delivers DC current directly to the vehicle's battery is incorporated off-board in the wall or pedestal mounted.

Charging Station: The charging station needed to safely deliver energy from the electric circuit to the vehicle, called electric vehicle support equipment (EVSE). The EVSE may at a minimum, be a specialized cordset that connects a household Level 1/120V socket to the vehicle; otherwise, the EVSE will include a cordset and a charging station (a wall or pedestal mounted box incorporating a charger and other equipment). Charging stations may include optional advanced features such as timers to delay charging until off-peak hours, communications equipment to allow the utility to regulate charging, or even electricity metering capabilities. Stakeholders are working on which features are best located on the EVSE or on the vehicle itself, and it is possible that redundant capabilities and features may be present in both the vehicle and EVSEs in the near future until these issues are worked out. EVSE and vehicle manufacturers are also working to ensure that current SAE-compliant "basic" EVSEs are charge-compatible with future grid-connected vehicles.

Dedicated Circuit: A Level 1 circuit is standard household current, 120V AC, rated at 15 or 20 A (12 or 16 A usable). A Level 2 circuit is rated at 208 to 240V and up to 80 A and is similar to the type of circuit that powers electric stoves (up to 50 A) and dryers (usually 30 A). Generally, Level 1 and 2 circuits used for electric vehicle recharging must be dedicated circuits, i.e., there cannot be other appliances on that circuit. For a Level 2 circuit, the homeowner or other user must install a charging station and will need a permit. A homeowner may choose to install the charger on a separately-metered circuit to take advantage of special electrical rates for off-peak charging, where available.

In addition to the costs of purchasing and installing charging equipment, charging station installation may include the costs of upgrading existing electrical panels and installing the electrical connection from the panel to the desired station location. These costs may be dramatically lowered if new construction incorporates the panel box and wiring required for charging stations, or even includes charging stations or outlets for charging stations as standard equipment.

The current costs of charging stations are highly variable depending on the level of service (and alternative power capabilities within these categories), location (individual residence, grouped residences, retail or business, parking lot or garage), level of sophistication of the station, and installation requirements, including electrical upgrading requirements. Estimated costs for charging stations are included in Table 3-118 below.

Table 3-118: Estimated Costs for Charging Stations Used in the 2010 TAR (2008$)

Level	Location	Equipment	Installation
1	Single Residence	$30- $200 (charge cord only, included at no cost to consumer with EV/PHEV) when an accessible household plug (e.g., in a garage or adjacent to a driveway) with a ground fault interrupter is already available	$400-$1000+ may be necessary depending on difficulty of installing a new circuit at the desired location, but in most cases, owners with sufficient panel capacity would opt for a more capable 220 VAC Level 2 installation instead of a Level 1 dedicated circuit because the additional installation cost is only marginally higher

2	Residential, Apartment Complex, or Fleet Depot[b]	3.3 kW EVSE (each): $300- $4,000 6.6 kW EVSE (each): $400- $4,000	3.3- 6.6 kW installation cost: $400-$2,300 without wiring/service panel upgrade, or $2,000-$5,000 with panel upgrade

refs: 77,78,79,80,a

[a] Detailed information on charger cost for each charging level and location and specific sources for cost estimates are available in the TAR, Appendix G.
[b] Level 2 EVSE installation costs vary considerably for single-family residences, multi-family residences, and fleet depots, depending upon the need for wiring and service panel upgrades. The range depicted here reflects the anticipated variability of these costs. However, EPRI estimates that the typical residential Level 2 installation costs to be approximately $1,500. See the TAR, Appendix G for additional information.

3.4.4.1 Application of charging level by vehicle type

The home charging availability for a specific consumer will need to be differentiated among EV/PHEVs with different battery capacity. The electric outlets in existing homes are most likely ready for Level 1 charging, which is about sufficient for fully recharging a PHEV20 SUV during normal nighttime, provided the outlet is not being heavily utilized by other loads. Shorter available charging time or owning a PHEV or an EV with a larger battery make the capability to fully charge overnight with a Level 1 system less likely, but upgrading to a Level 2 system in such cases will allow full recharge to happen more quickly.

Table 3-119 shows the application of charge level by vehicle type and range. Charging types were chosen based on nominal time to charge a fully-depleted battery in a vehicle with 0% net weight reduction. Charge times exceeding 9 hours for Level 1 were deemed unacceptable and Level 2 charging was specified. For charge times between 6 hours and 9 hours on Level 1, a mix of Level 1 and Level 2 was specified. This was done to recognize the varying consumer value of faster, but more expensive, Level 2 charging over Level 1 charging.

Table 3-119: Charger Type by Vehicle Technology and Class

EPA Vehicle Class	PHEV20	PHEV40	EV75	EV100	EV150
Small car	100% L1	25% L1 75% L2	100% L2	100% L2	100% L2
Standard Car	100% L1	10% L1 90% L2	100% L2	100% L2	100% L2
Large Car	100% L1	100% L2	100% L2	100% L2	100% L2
Small MPV	100% L1	100% L2	100% L2	100% L2	100% L2
Large MPV	100% L1	100% L2	100% L2	100% L2	100% L2
Truck	50% L1 50% L2	100% L2	100% L2	100% L2	100% L2

For this final rule, consistent with the proposal, the resultant costs associated with in-home chargers and installation of in-home chargers are included in the total cost for an EV and or PHEV. However, here we summarize specially the costs for chargers and installation labor. The agencies have estimated the DMC of a level 1 charge cord at $31 (2010$) based on typical costs of similar electrical equipment sold to consumers today and that for a level 2 charger at $204 (2010$). Labor associated with installing either of these chargers is estimated at $1,020 (2010$). Further, we have estimated that all PHEV20 vehicles (PHEVs with a 20 mile range) would be charged via a level 1 charger and that all EVs, regardless of range, would be charged via a level 2 charger. For the PHEV40 vehicles (PHEVs with a 40 mile range), we have estimated that: 25% of small cars would be charged with a level 1 charger with the remainder charged via a level 2 charger; 10% of standard cars would be charged with a level 1 charger with the remainder charged via a level 2 charger; and all remaining PHEV 40 vehicles would be charged via a level 2 charger. All costs presented here are considered applicable in the 2025 model year. The agencies have applied the learning curve presented in Section 3.2.3 to all charger costs. The agencies have also applied a High1 ICM of 1.56 through 2024 then 1.34 thereafter. Installation costs, being labor costs, have no learning impacts or ICMs applied. The resultant costs are shown in Table 3-120.

Table 3-120 Costs for EV/PHEV In-home Chargers (2010$)

Cost type	Technology	EPA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	PHEV20 Charger	All	$60	$48	$48	$38	$38	$38	$38	$38	$31
DMC	PHEV40 Charger	Small car	$314	$251	$251	$201	$201	$201	$201	$201	$161
		Std car	$365	$292	$292	$233	$233	$233	$233	$233	$187
		Large car Small MPV	$398	$319	$319	$255	$255	$255	$255	$255	$204
DMC	EV Charger	All	$398	$319	$319	$255	$255	$255	$255	$255	$204
IC	PHEV20 Charger	All	$19	$18	$18	$18	$18	$18	$18	$18	$11
IC	PHEV40 Charger	Small car	$100	$96	$96	$93	$93	$93	$93	$93	$55
		Std car	$117	$112	$112	$108	$108	$108	$108	$108	$64
		Large car Small MPV	$128	$122	$122	$118	$118	$118	$118	$118	$70
IC	EV Charger	All	$128	$122	$122	$118	$118	$118	$118	$118	$70
TC	PHEV20 Charger	All	$79	$66	$66	$56	$56	$56	$56	$56	$41
TC	PHEV40 Charger	Small car	$414	$347	$347	$294	$294	$294	$294	$294	$216
		Std car	$481	$404	$404	$342	$342	$342	$342	$342	$251
		Large car Small MPV	$526	$441	$441	$373	$373	$373	$373	$373	$274
TC	EV Charger	All	$526	$441	$441	$373	$373	$373	$373	$373	$274
TC	Charger labor	All	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020	$1,020

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.5 Other Technologies Assessed that Reduce CO2 and Improve Fuel Economy

In addition to the technologies already mentioned above, the other technologies generally considered in the agencies' analysis are described below. They fall into five broad categories: engine technologies, transmission technologies, vehicle technologies, electrification/accessory technologies, hybrid technologies and mass reduction

3.4.5.1 Lower Rolling Resistance Tires

Tire rolling resistance is the frictional loss associated mainly with the energy dissipated in the deformation of the tires under load and thus influences fuel economy and CO_2 emissions. Other tire design characteristics (*e.g.*, materials, construction, and tread design) influence durability, traction (both wet and dry grip), vehicle handling, and ride comfort in addition to rolling resistance. A typical low rolling resistance tire's attributes could include: increased specified tire inflation pressure, material changes, and tire construction with less hysteresis, geometry changes (*e.g.*, reduced aspect ratios), and reduction in sidewall and tread deflection. These changes would generally be accompanied with additional changes to vehicle suspension tuning and/or suspension design.

The agencies expect that greater reductions in tire rolling resistance will be possible during the rulemaking timeframe than are currently available, as tire manufacturers continue to improve their products in order to meet increasing demand by auto OEMs for tires that contribute more to their vehicles' fuel efficiency. Thus, for this final rule, consistent with the proposal, the agencies considered two "levels" of lower rolling resistance tires. The first level ("LRR1") is defined as a 10 percent reduction in rolling resistance from a base tire, which was estimated to be a 1 to 2 percent effectiveness improvement in MYs 2012-2016 final rule. Based on the 2011 Ricardo study the agencies are now using 1.9 percent effectiveness improvement for LRR1for all vehicle classes. LRR1 tires are widely available today, and appear to comprise a larger and larger portion of tire manufacturers' product lines as the technology continues to improve and mature. The second level ("LRR2") is defined as a 20 percent reduction in rolling resistance from a base tire, yielding an estimated 3.9 percent effectiveness improvement. In the CAFE model this results in a 2.0 percent incremental effectiveness increase from LRR1. LRR2 represents an additional level of rolling resistance improvement beyond what the agencies considered in the MYs 2012-2016 rulemaking analysis. NHTSA assumed that the increased traction requirements for braking and handling for performance vehicles could not be fully met with the ROLL2 designs in the MYs 2017-2025 timeframe. For this reason the CAFE model did not apply ROLL2 to performance vehicle classifications. However, the agency did assume that tractions requirement for ROLL1 could be met in this timeframe and thus allowed ROLL1 to be applied to performance vehicle classifications in the MYs 2017-2025 timeframe.

In the 2012-2016 light duty vehicle rule, the agencies estimated the incremental DMC at an increase of $5 (2007$) per vehicle. This included costs associated with five tires per vehicle, four primary and one spare tire. There is no learning applied to this technology due to the commodity based nature of this technology. Looking forward from 2016, the agencies continue to apply this same estimated DMC adjusted for 2010 dollars.[bbb] The agencies consider LRR1 to be fully learned out or "off" the learning curve (*i.e.*, the DMC does not change year-over-year) and have applied a low complexity ICM of 1.24 through 2018, and then 1.19 thereafter, due to the fact that this technology is already well established in the marketplace.

To analyze the feasibility and cost for a second level of rolling resistance improvement, EPA, NHTSA, and CARB met with a number of the largest tire suppliers in the United States. The suppliers were generally optimistic about the ability to reduce tire rolling resistance in the future without the need to sacrifice traction (safety) or tread life (durability). Suppliers all generally stated that rolling resistance levels could be reduced by 20 percent relative to today's tires by MY 2017. As such, the agencies agreed, based on these discussions, to consider LRR2 as initially available for purposes of this analysis in MY 2017, but not widespread in the marketplace until MYs 2022-2023. In alignment with introduction of new technology, the agencies limited the phase-in schedule to 15 percent of a manufacturer's fleet starting in 2017, and did not allow complete application (100 percent of a manufacturer's fleet) until 2023. The agencies believe that this schedule aligns with the necessary efforts for production implementation, such as system and electronic system calibration and verification.

LRR2 technology does not yet exist in the marketplace today, making cost estimation challenging without disclosing potentially confidential business information. To develop a transparent cost estimate, the agencies relied on LRR1 history, costs, market implementation, and information provided by the 2010 NAS report. The agencies assumed low rolling resistance technology ("LRR1") first entered the marketplace in the 1993 time frame with more widespread adoption being achieved in recent years, yielding approximately 15 years to maturity and widespread adoption. Then, using MY 2017 as the starting point for market entry for LRR2 and taking into account the advances in industry knowledge and an assumed increase in demand for improvements in this technology, the agencies interpolated DMC for LRR2 at $10 (2010$) per tire, or $40 ($2010) per vehicle. This estimate is generally fairly consistent with CBI suggestions by tire suppliers. The agencies have not included a cost for the spare tire because we believe manufacturers are not likely to include a LRR2 as a spare given the $10 DMC. In some cases and when possible pending any state-level requirements, manufacturers have removed spare tires replacing them with tire repair kits to reduce both cost and weight associated with a spare tire.[81] The agencies consider this estimated cost for LRR2 to be applicable in MY 2021. Further, the agencies consider LRR2 technology to be on the steep portion of the learning curve where costs would be reduced quickly in a relative

[bbb] As noted elsewhere in this chapter, we show dollar values to the nearest dollar. However, dollars and cents are carried through each agency's respective analysis. Thus, while the cost for lower rolling resistance tires in the 2012-2016 final rule was shown as $5, the specific value used in that rule was $5.15 (2007$) and is now $5.40 (2010$). We show $5 for presentation simplicity.

short period of time. The agencies have applied a low complexity ICM of 1.24 through 2024, and then 1.19 thereafter. The ICM timing for LRR2 is different from that for LRR1 because LRR2 is brand-new for this rulemaking and is not yet being implemented in the fleet. The resultant costs are shown in Table 3-121. Note that both LRR1 and LRR2 are incremental to the baseline system, so LRR2 is not incremental to LRR1.

Table 3-121 Costs for Lower Rolling Resistance Tires Levels 1 & 2 (2010$)

Cost type	Lower Rolling Resistance Tire Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Level 1	$5	$5	$5	$5	$5	$5	$5	$5	$5
DMC	Level 2	$63	$63	$51	$51	$40	$39	$38	$37	$36
IC	Level 1	$1	$1	$1	$1	$1	$1	$1	$1	$1
IC	Level 2	$10	$10	$10	$10	$10	$10	$10	$10	$8
TC	Level 1	$7	$7	$6	$6	$6	$6	$6	$6	$6
TC	Level 2	$73	$73	$60	$60	$50	$49	$48	$47	$44

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost
Note that both levels of lower rolling resistance tires are incremental to today's baseline tires.

Given that the final standards cover such a long timeframe, the agencies also considered introducing a third level of rolling resistance reduction ("LRR3"), defined as a 30 percent reduction in rolling resistance. The agencies evaluated the potential of LRR3 entering the marketplace during this final rulemaking timeframe.

Tire technologies that enable improvements of 10 and 20 percent have been in existence for many years. Achieving improvements up to 20 percent involves optimizing and integrating multiple technologies, with a primary contributor being the adoption of a silica tread technology.[82] This approach was based on the use of a new silica along with a specific polymer and coupling agent combination. The use of the polymer, coupling agent and silica was known to reduce tire rolling resistance at the expense of tread wear, but new approach using novel silica reduced the tread wear tradeoff. Tire suppliers have indicated there are one or more innovations/inventions that they expect to occur in order to move the industry to the next quantum reduction of rolling resistance. However, based on the historical development and integration of tire technologies, there appears to be little evidence supporting improvements beyond LRR2 by 2025. Therefore, the agencies decided not to incorporate LRR3 at this time.

The agencies sought comment on whether we should consider application of a 30 percent reduction from today's rolling resistance levels being available for mass production implementation by MY 2025 or sooner. The agencies also sought comment on the viability of this technology, maturity by MY 2025, as well as market introduction timing and the technological ways that this level of rolling resistance improvement will be achieved without any tradeoffs in terms of vehicle handling capability and tire life from what consumers expect today. Finally, the agencies sought cost information regarding the potential incorporation of LRR3 relative to today's costs as well as during the timeframe covered by this final rule. No comments were submitted on any of these topics.

3.4.5.2 Low Drag Brakes

Low drag brakes reduce the sliding friction of disc brake pads on rotors when the brakes are not engaged because the brake pads are pulled away from the rotating disc either by mechanical or electric methods

The 2012-2016 final rule and TAR estimated the effectiveness of low drag brakes to be as much as 1 percent. NHTSA and EPA have slightly revised the effectiveness down to 0.8 percent based on the 2011 Ricardo study and updated lumped-parameter model.

In the 2012-2016 rule, the agencies estimated the DMC at $57 (2007$). This DMC becomes $59 (2010$) for this analysis after adjusting to 2010 dollars. The agencies consider low drag brake technology to be off the learning curve (i.e., the DMC does not change year-over-year) and have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. The resultant costs are shown in Table 3-122.

Table 3-122 Costs for Low Drag Brakes (2010$)

Cost type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$59	$59	$59	$59	$59	$59	$59	$59	$59
IC	$14	$14	$11	$11	$11	$11	$11	$11	$11
TC	$74	$74	$71	$71	$71	$71	$71	$71	$71

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.5.3 Front or Secondary Axle Disconnect for Four-Wheel Drive Systems

Energy is required to continually drive the front, or secondary, axle in a four-wheel drive system even when the system is not required during most operating conditions. This energy loss directly results in increased fuel consumption and CO_2 emissions. Many part-time four-wheel drive systems use some type of front axle disconnect to provide shift-on-the-fly capabilities. The front axle disconnect is normally part of the front differential assembly. As part of a shift-on-the-fly four-wheel drive system, the front axle disconnect serves two basic purposes. First, in two-wheel drive mode, it disengages the front axle from the front driveline so the front wheels do not turn the front driveline at road speed, saving wear and tear. Second, when shifting from two- to four-wheel drive "on the fly" (while moving), the front axle disconnect couples the front axle to the front differential side gear only when the transfer case's synchronizing mechanism has spun the front driveshaft up to the same speed as the rear driveshaft. Four-wheel drive systems that have a front axle disconnect typically do not have either manual- or automatic-locking hubs. To isolate the front wheels from the rest of the front driveline, front axle disconnects use a sliding sleeve to connect or disconnect an axle shaft from the front differential side gear. NHTSA and EPA are not aware of any manufacturer offering this technology in the U.S. today on unibody frame vehicles; however, it is possible this technology could be introduced by manufacturers within the MYs 2017-2025 time period.

The 2012-2016 final rule estimated an effectiveness improvement of 1.0 to 1.5 percent for axle disconnect. Based on the 2011 Ricardo report, NHTSA and EPA refined this range to 1.2 to 1.4 percent.

In the 2012-2016 rule, the agencies estimated the DMC at $78 (2007$) which was considered applicable to the 2015MY. This DMC becomes $82 (2010$) for this analysis after adjusting to 2010 dollars. The agencies consider secondary axle disconnect technology to be on the flat portion of the learning curve and have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. The resultant costs are shown in Table 3-123.

Table 3-123 Costs for Secondary Axle Disconnect (2010$)

Cost type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$78	$76	$75	$73	$72	$70	$69	$68	$66
IC	$20	$20	$16	$16	$16	$16	$16	$16	$16
TC	$98	$96	$91	$89	$88	$86	$85	$83	$82

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

3.4.5.4 Aerodynamic Drag Reduction

Many factors affect a vehicle's aerodynamic drag and the resulting power required to move it through the air. The overall drag force can be simplified as proportional to vehicle's frontal area, vehicle's drag coefficient, air density and the second order of vehicle's velocity. Therefore reducing vehicle's frontal area and drag coefficient can reduce fuel consumption and CO_2 emissions. Although frontal areas tend to be relatively similar within a vehicle class (mostly due to market-competitive size requirements), significant variations in drag coefficient can be observed. Significant changes to a vehicle's aerodynamic performance may need to be implemented during a redesign (*e.g.*, changes in vehicle shape). However, shorter-term aerodynamic reductions, with a somewhat lower effectiveness, may be achieved through the use of revised exterior components (typically at a model refresh in mid-cycle) and add-on devices that are currently being applied. The latter list would include revised front and rear fascias, modified front air dams and rear valances, addition of rear deck lips and underbody panels, and lower aerodynamic drag exterior mirrors.

The 2012-2016 final rule estimated that a fleet average of 10 to 20 percent total aerodynamic drag reduction is attainable which equates to incremental reductions in fuel consumption and CO_2 emissions of 2 to 3 percent for both cars and trucks. These numbers are generally supported by the Ricardo study and public technical literature and therefore NHTSA and EPA are retaining these estimates, as confirmed by joint review, for the purposes of this final rule, consistent with the proposal. Importantly, the effectiveness values presented here represent two-cycle effectiveness. Because active aerodynamic technologies (i.e., aero level 2) provide additional off-cycle benefits, both agencies apply an off-cycle credit value to the technology. Off-cycle credits are discussed in Chapter 5 of this Joint TSD.

For this final rule, consistent with the proposal, the agencies considered two levels of aero improvements. The first level is that discussed in the 2012-2016 final rule and the 2010 TAR and includes such body features as air dams, tire spats, and perhaps one underbody panel. In the 2012-2016 rule, the agencies estimated the DMC of aero-level 1 at $39 (2007$). This DMC becomes $41 (2010$) for this analysis, applicable in the 2015MY. The agencies consider aero-level 1 technology to be on the flat portion of the learning curve and have applied a low complexity ICM of 1.24 through 2018 then 1.19 thereafter.

The second level of aero—level 2 which includes such body features as active grille shutters[ccc], rear visors, larger under body panels or low-profile roof racks —was discussed in the 2010 TAR where the agencies estimated the DMC at $120 (2008$) incremental to the baseline vehicle. The agencies inadvertently used that cost as inclusive of aero-level 1 technologies when it should have been incremental to aero-1 technologies. As a result, the agencies now consider the TAR cost to more appropriately be incremental to aero-level 1 with a DMC for this analysis of $123 (2010$). The agencies consider this cost to be applicable in the 2015MY. Further, the agencies consider aero-level 2 technology to be on the flat portion of the learning curve. The agencies have applied a medium complexity ICM of 1.39 through 2024 then 1.29 thereafter. The timing of the aero-level 2 ICMs is different than that for the level 1 technology because the level 2 technology is newer and not yet being implemented in the fleet. The resultant costs are shown in Table 3-124.

Table 3-124 Costs for Aerodynamic Drag Improvements – Levels 1 & 2 (2010$)

Cost type	Aero Technology	Incremental to	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Level 1	Baseline	$39	$38	$37	$37	$36	$35	$35	$34	$33
DMC	Level 2	Aero-level 1	$117	$115	$112	$110	$108	$106	$104	$102	$100
IC	Level 1	Baseline	$10	$10	$8	$8	$8	$8	$8	$8	$8
IC	Level 2	Aero-level 1	$47	$47	$47	$47	$47	$47	$47	$47	$35
TC	Level 1	Baseline	$49	$48	$45	$45	$44	$43	$42	$42	$41
TC	Level 2	Aero-level 1	$164	$162	$160	$157	$155	$153	$150	$148	$135
TC	Level 2	Baseline	$213	$210	$205	$202	$199	$196	$193	$190	$176

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Because a large percent of the performance vehicles already have some level of aerodynamic treatments, when running the CAFE model NHTSA only applies level 1 of aerodynamic treatment to these vehicles. Also for specific vehicles, such as Toyota Prius, which already have extensive aerodynamic treatment, the level of the aerodynamic that could be further applied by NHTSA in the CAFE model is limited in the market input file.

[ccc] For details on how active aerodynamics are considered for off-cycle credits, see TSD Chapter 5.2.2.

3.4.5.5 Mass Reduction

From 1987-2011, there has been a generally increasing trend in the weight of the light duty vehicle fleet as shown in Figure 3-26 from EPA's Fuel Economy Trends Report[83]. A number of factors have contributed to this weight increase, including the choices of manufacturers and consumers to build and purchase larger vehicles, including heavier trucks, SUVs, and CUVs. Also contributing to this weight increase has been an increase in vehicle content including: safety features (air bags, antilock brakes, energy absorbent and intrusion resistant vehicle structures, etc.), noise reduction (additional damping material), added comfort and convenience features (air conditioning, power locks and windows), luxury features (infotainment systems, powered seats), etc.

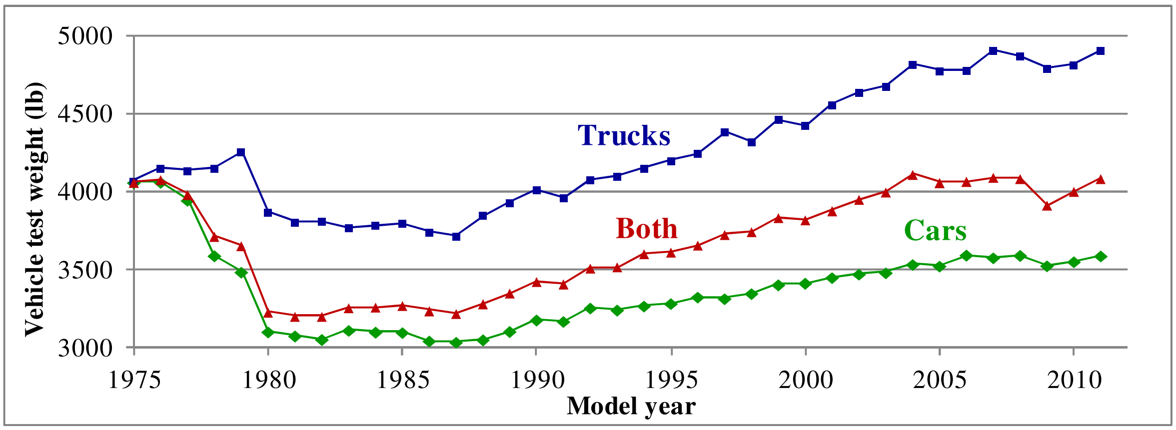


Figure 3-26 Light duty fleet weight trends: 1975-2011

Despite this increase in weight, the average acceleration of vehicles has grown steadily faster without any marked or consistent reduction in fuel economy since 1987**,** as shown in Figure 3-27. This combination of increased vehicle performance, stable fuel economy, and increased vehicle weight has been partially enabled by the development and adoption of more efficient technologies, especially in engines and transmissions. The impressive improvements in powertrain efficiency during this period have offset increases in energy consumption that result from improvements in weight carrying, towing and volume capacities, safety, consumer features, vehicle refinement, and acceleration performance.

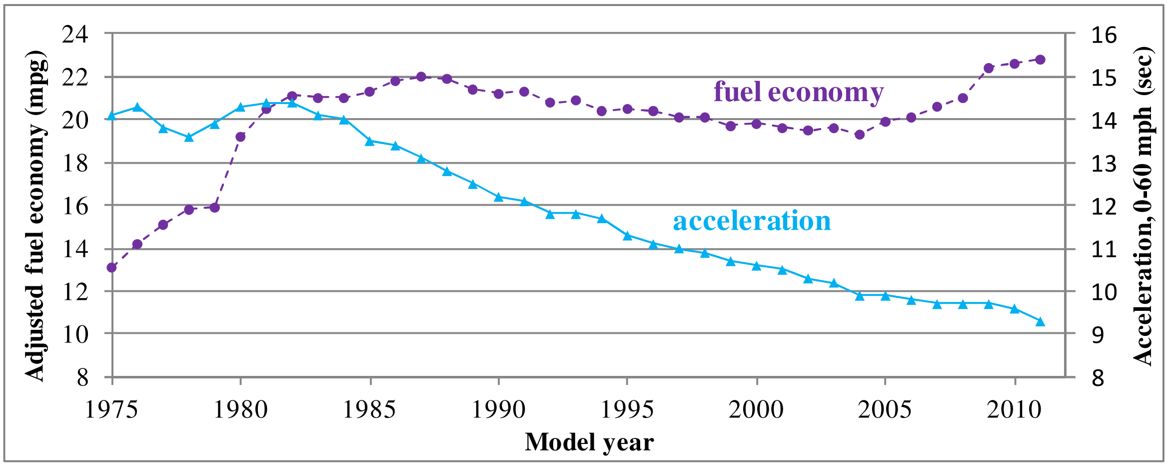


Figure 3-27 Light duty fleet trends for acceleration and fuel economy: 1975-2011[84]

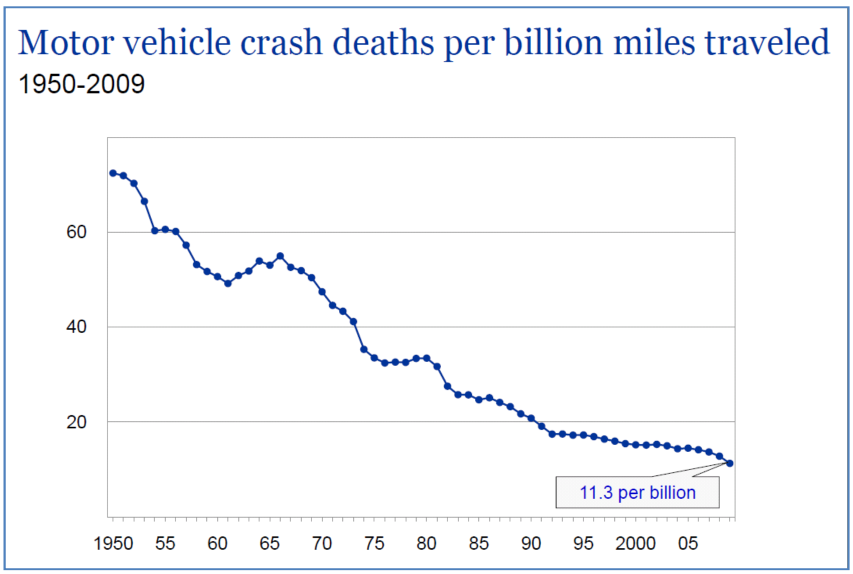
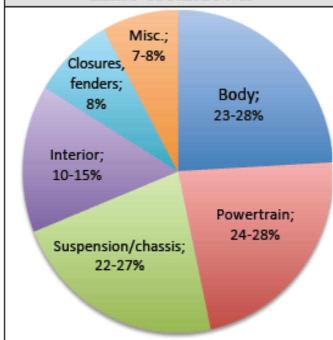


Figure 3-28 U.S. Vehicle Fatality Rates for the past 60 years[85]

Vehicle mass reduction (also referred to as "down-weighting" or 'light-weighting"), reduces the energy needed to overcome inertial forces, thus yielding lower fuel consumption and GHG emissions. While keeping everything else constant, a lighter vehicle will require less energy to operate than a heavier vehicle. Mass reduction can be achieved through a number of approaches described below, even while maintaining vehicle size. Alternatively, mass reduction can also be achieved by vehicle "downsizing" which involves reducing vehicle exterior dimensions, such as shifting from a midsize vehicle to a compact vehicle. Consistent with the proposal, the agencies did not analyze downsizing as a mass reduction strategy in this analysis for the final rule. In part, this is because a manufacturer's ability to downsize its vehicles is constrained by consumer preferences (such as for interior passenger or cargo volume), which are in turn influenced by many factors that are difficult to predict in the future, such as the consumer's utility needs, fuel prices, economic conditions, etc. Also, the final CAFE and GHG emission standards are based on vehicle footprint (the area bounded by where the four tires contract the ground), and assign higher fuel economy targets (and lower CO_2 emission targets) for vehicles with smaller footprints and lower fuel economy targets (and higher CO_2 emission targets) for vehicles with larger footprints. As discussed in Chapter 2 of the joint TSD, the agencies believe the shape of the footprint-based target curves will not create incentives for manufacturers to either upsize or downsize their vehicles. Based on these considerations, the agencies are assuming that manufacturers will favor mass reduction through material substitution, design optimization, and adopting other advanced manufacturing technologies rather than compromising a vehicle's attributes and functionality, such as occupant or cargo space, vehicle safety, comfort, acceleration, etc. Consequently, the compliance paths the agencies have investigated for the promulgated standards do not include downsizing.

Mass reduction has an important relationship with vehicle powertrain selection and sizing. Vehicle powertrain selection depends on an OEM's product strategy, and may include a variety of options such as naturally aspirated engines, boosted and downsized gasoline engines, diesel engines, or vehicle electrification (P/H/EV) Regardless of the strategy selected, vehicle mass reduction for non-powertrain systems is an important enabler to further reduce vehicle fuel consumption and reduce the size of the powertrain system. The term "glider" refers to a complete vehicle minus the powertrain. Figure 3-29 illustrates the mass breakdown by system for a typical vehicle[86]. The non-powertrain systems normally account for 75 percent of vehicle weight. The agencies have accounted for some of the costs of engine mass reduction when applying engine downsizing technologies. The agencies have also accounted for the amount of mass change due to the application of hybrid and electrification technologies in the vehicle electrification sections. Therefore, this section focuses on both the mass reduction of the glider as well as mass reduction technologies that are specifically targeted at reducing the weight of the powertrain.[ddd] rather than on mass reduction resulting from powertrain efficiency improvements. An example of a mass reduction technology for the powertrain that is not related to powertrain efficiency improvement is material substitution, such as changing the engine block from cast iron to aluminum or changing the size of the fuel tank.). Mass reduction is calculated for both the glider and the vehicle including powertrain in the studies sponsored by the agencies as shown later in this section.

[ddd] Rather than on mass reduction resulting from powertrain efficiency improvements, such as in the case of adding a turbocharger to a downsized engine.



Approximate vehicle mass breakdown[a]	System	Major components in system
(see chart above)	Body-in-white	Passenger compartment frame, cross and side beams, roof structure, front-end structure, underbody floor structure, panels
	Powertrain	Engine, transmission, exhaust system, fuel tank
	Chassis	Chassis, suspension, tires, wheels, steering, brakes
	Interior	Seats, instrument panel, insulation, trim, airbags
	Closures	Front and rear doors, hood, lift gate
	Miscellaneous	Electrical, lighting, thermal, windows, glazing

[a] *Based on Stodolsky et al, 1995a; Bjelkengren, 2008; Lotus Engineering, 2010; the actual system definitions and system component inclusion can vary, and percentage weight breakdown can vary substantially by vehicle*

Figure 3-29 Vehicle system mass approximation

A vehicle can be divided into 6 major systems, which are shown in Figure 3-29. Mass reduction can potentially be applied to any of a vehicle's subsystems, including the engine, exhaust system, transmission, chassis, suspension, brakes, body, closure panels, glazing, seats and other interior components, engine cooling systems, and HVAC systems. While manufacturers may reduce the mass of some individual components during a vehicle refresh, they generally undertake larger amounts of mass reduction systematically and more broadly across all vehicle systems when redesigning a vehicle. In the redesign process, OEMs normally set weight targets by benchmarking other vehicles in the same segment and projecting weight trends into the future, and then identifying targets for all components and subsystems that support achieving the target. The agencies believe this holistic approach, which takes into consideration all secondary mass savings, is likely the most effective way for OEMs to achieve large amounts of mass reduction.

During a vehicle redesign where mass reduction is a strategic vehicle program goal, OEMs can consider modular systems design, secondary mass effects, multi-material concepts, and new manufacturing processes to help optimize the design. There are several studies in the public domain that illustrate the potential for these approaches to achieve significant amounts of mass reduction, although it is important to also recognize that the studies use some assumptions that do not account for some of the considerations that are important to manufacturers. One example is the need to share some components across platforms to manage cost and part complexity for assembly and service, which limits the ability to optimize the amount of mass reduction on every vehicle component. Care must also be taken in any study to assure that vehicle functionality and performance, such as stiffness, NVH, safety and vehicle dynamics, continue to meet manufacturer objectives and consumer demands. It is important for design studies to use tools such as simulation modeling to assess the design's ability to meet functionality and performance targets. In this rulemaking, the agencies have targeted to preserve vehicle function and performance in their analysis of mass reduction.

An example of this approach is illustrated in Figure 3-30, which summarizes the results of the 2010 phase I Lotus Engineering mass reduction study of a Toyota Venza.

Mass-reduction features, findings	• Redesign conventional mid-size vehicle for mass optimization, with two redesign architectures • Low Development vehicle technology with industry-leading manufacturing techniques that were deemed feasible for 2014 (for model year 2017 production) for assembly at existing facilities • High Development vehicle technology, with modifications to conventional joining and assembly processes that were deemed feasible for 2017 (for model year 2020) production • Extensive use of material substitution with high-strength steel, advanced high–strength steel, aluminum, magnesium, plastics and composites throughout vehicles • Conservative use of emerging design and parts integration concepts to minimize technical risk • Using synergistic total vehicle substantial mass reduction opportunities found at minimized piece costs • The Low Development vehicle was found to have likely piece cost reductions, whereas the High Development vehicle had nominal estimated cost increase of 3% (with potential for cost reduction)
Mass-reduction impact	• Body structure reduction for Low Development Vehicle: 55 lb (6.6%) • Body structure reduction for High Development Vehicle: 356 lb (42%) • Overall glider reduction for Low Development Vehicle: 538 lb (19%) • Overall glider reduction for High Development Vehicle: 1096 lb (39%) • Overall vehicle reduction for Low Development Vehicle (with hybrid powertrain): 657 lb (17.6%) • Overall vehicle reduction for High Development Vehicle (with hybrid powertrain): 1209 lb (32%)
Status	• Engineering design study conducted by Lotus Engineering • First phase of project, development of two mass-reduced vehicle designs completed in April 2010 • Second phase to test structural integrity, impact load paths, crash worthiness to validate the vehicle designs.
Source	• Lotus Engineering, Inc. 2010. An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program
Illustrations	

Figure 3-30 Example of a holistic vehicle redesign study from Lotus Engineering[87]

Mass reduction can be considered in terms of the "percent by which the redesigned vehicle is lighter than the previous version," recognizing that the value likely represents both "primary" mass reduction (that which the manufacturer set out to make lighter), and "secondary" mass reduction (from ancillary systems and components that can now be lighter due to the primary mass reductions).

As summarized by NAS in its 2011 report,[88] there are two key strategies for primary mass reduction: 1) changing the design to use less material or 2) substituting lighter materials for heavier materials. The first key strategy of using less material compared to the baseline component can be achieved by optimizing the design and structure of the component, system or vehicle structure. For example, a number of "body on frame" vehicles have been redesigned with a lighter "unibody" construction, eliminating components, reducing the weight of the body structure, and resulting in significant reductions in overall mass and related costs. The unibody design currently dominates the passenger car segment and has increased penetration into what used to be mostly body-on-frame vehicles, such as SUVs.

This technique was used in the 2011 Ford Explorer redesign, which also employed the extensive use of high strength steels.[89] Figure 3-31 depicts body-on-frame and unibody designs for two sport utility vehicles.

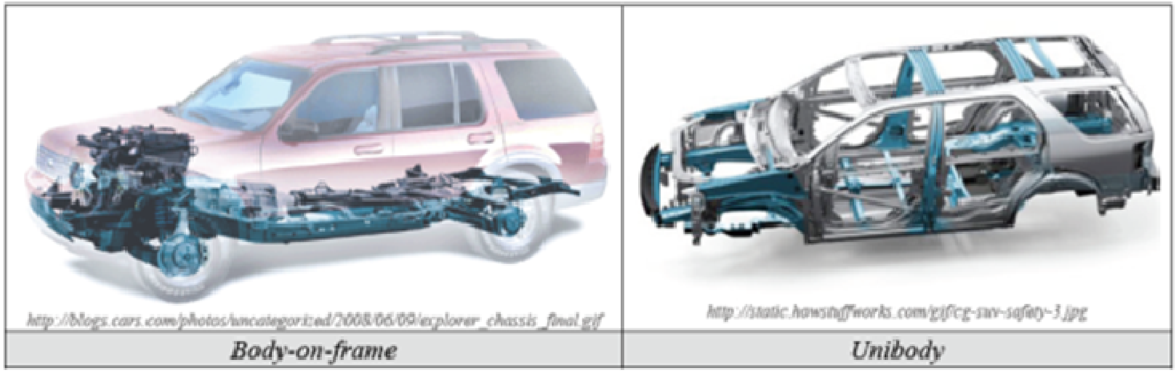


Figure 3-31 Illustration of Body-on-Frame (BoF) and Unibody vehicle construction

To further reduce mass inefficiencies in vehicle design, vehicle manufacturers are using continually-improving Computer Aided Engineering (CAE) tools. For example, the Future Steel Vehicle (FSV) project[90] sponsored by WorldAutoSteel used three levels of optimization: topology optimization, low fidelity 3G (Geometry Grade and Gauge) optimization, and sub-system optimization, to achieve 30 percent mass reduction in the body structure of a vehicle with a mild steel unibody structure (see Figure 3-32). Designs similar to those proposed in the FSV project have been applied in production vehicles, such as the B-pillar of 2010 Ford Focus.[91]

2.4 T4: Body Structure Sub-System Optimisation

The final design attained from the LF3G optimisation was used as the basis for the sub-system optimisation, as well as the source of the boundary conditions. Load path mapping was conducted on the model to identify the most dominant structural sub-systems in the body structure. Load path mapping considers the dominant loads in the structural sub-systems for each of the load cases as shown in Figure 2-7.

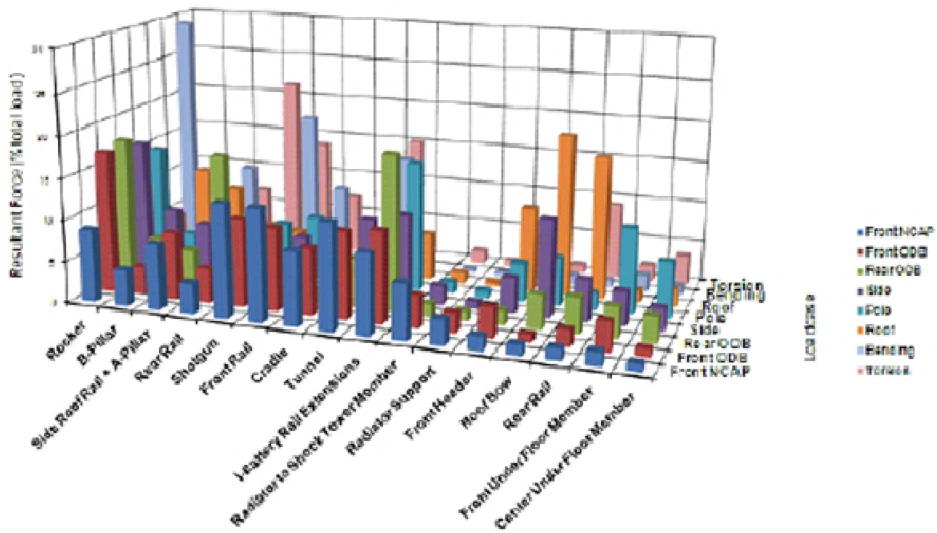


Figure 2-7: T4 Load Path Mapping – Major Load Path Components

Based on load path mapping, seven structural sub-systems (Figure 2-8) were selected for further optimisation using the spectrum of FSV's potential manufacturing technologies.

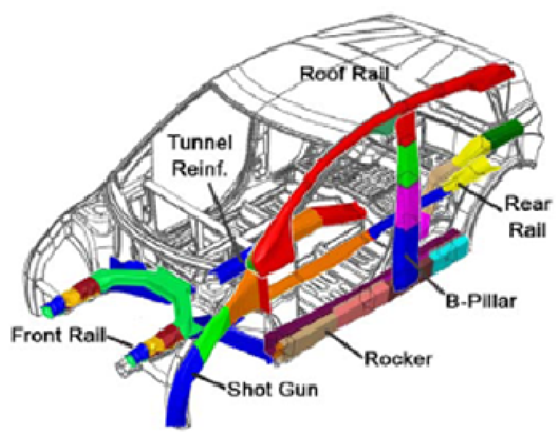


Figure 2-8: Structural Sub-Systems Selected

FutureSteelVehicle WorldAutoSteel

Figure 3-32 Example of vehicle body load path mapping for mass optimization

Vehicle manufacturers have long used these continually-improving CAE tools to optimize vehicle designs. But because any design must meet component and system functionality and manufacturability targets, there are practical limitations to the amount of additional mass reduction that can be achieved through optimization. For example, an optimization program would need to account for safety, stiffness, NVH, manufacturing, and other requirements to assure the design is suitable for its intended function and for mass production. Additionally, ultimate optimization of vehicle design for mass reduction may be limited by an OEM's use of shared components and common platform for multiple vehicle models. While optimization may concentrate on the vehicle that has the largest production volume for a platform, designs must also support the most demanding functional requirements of all of the vehicles that share that platform, or those functional requirements will not be met. In addition, the engineering resources and capital for tooling and equipment that would be needed to optimize every vehicle component at each redesign affects the ability to fully optimize a new vehicle to achieve all of the theoretically possible secondary mass reduction. Therefore, some level of mass inefficiency will inherently exist on many or all of the vehicles that share a platform. The agencies sought comment and information in the NPRM on the degree to which shared vehicle components and architectures affect the feasible amount of mass reduction and the cost for mass reduction relative to what could be achieved if mass reduction was optimized for a single vehicle design. Volkswagen confirmed in its comments that with platform sharing, "a weight reduction technology which may be acceptable in terms of price or performance for one model may disrupt the economics or utility of another."[92]

Using less material can also be achieved through improving the manufacturing process, such as by using improved joining technologies and parts consolidation. This method is often used in combination with applying new materials. For example, more precise manufacturing techniques such as laser welding may reduce the flange size necessary for welding, and thus marginally decrease the mass of an assembly. Also, when complex assemblies are constructed from fewer pieces, the mass of the assembly tends to be lower. However, while synergies in mass reduction certainly exist, and while certain technologies can enable one another (*e.g.*, parts consolidation and molding of advanced composites), others may be incompatible (*e.g*., laser welding and magnesium casting).

The second key strategy to reduce mass of an assembly or component involves the substitution of lower density and/or higher strength materials. Table 3-125 shows material usage typical of contemporary high-volume vehicles. Material substitution includes replacing materials, such as mild steel, with higher-strength and advanced steels, aluminum, magnesium, and composite materials. The substitution of advanced high strength steel (AHSS) for mild steel can reduce the mass of a strength-critical part because the gauge of the AHSS components can be reduced, despite the fact that the densities of the materials are not significantly different. Aluminum has also been used over the years in a variety of components, such as vehicle closures, suspension parts, engine cradles, etc. Aluminum has one third the density of steel and therefore can provide a notable amount of mass reduction. Changing parts from steel to aluminum generally requires part redesign, and extra material may have to be added for strength or durability. Aluminum also has a shorter fatigue life than steel, and therefore the alloy selected and the application must be carefully considered. Magnesium can provide additional mass reduction as it has lower density than aluminum. It has been used for instrument panel cross-car beams by several OEMs for a number of years. It has also been used in an engine block produced by BMW for several years. Its brittle nature must be considered, however, when selecting the alloy and the application within the vehicle.

Table 3-125 Distribution of Material in Typical Contemporary Vehicles (e.g., Toyota Camry or Chevrolet Malibu)[93]

Material	Comments	Approximate Content in Cars Today, by Weight (percent)
Iron and mild steel	Under 480 Mpa	55
High-strength steel	≥ 480 Mpa (in body structure)	15
Aluminum	No aluminum closure panels; aluminum engine block and head and wheels	10
Plastic	Miscellaneous parts, mostly interior trim, light lenses, facia, instrument panel	10
Other (magnesium, titanium, rubber, etc.)	Miscellaneous parts	10

Automobiles also utilize a wide range of plastic types, including polypropylenes, polyesters, and vinyl esters. These materials are utilized in hatches, roofs, interior panels, instrument panels, and hundreds of other parts. Although primarily used in nonstructural vehicle components, plastics have continued to make in-roads in bumper systems and in composite beam applications, and some studies have found potential to supplant structural beams and frame components. Lighter plastics have also been developed by the industry, and the application of these materials has been increasing.

Included in the category of plastics are composites like glass fiber and carbon fiber reinforced polymers. While these more costly advanced materials have primarily been used in a limited number of low production volume vehicle applications, some manufacturers are considering these composites for broader use. While these materials currently have the potential to be applied to components with little or no exposure to impact pulses, the advanced microstructure and limited industry experience may make these longer-term solutions. For example, advanced composite materials (such as carbon fiber-reinforced plastic), depending on the specific fiber, matrix, reinforcement architecture, and processing method, can be subject to dozens of competing damage and failure mechanisms that may complicate a manufacturer's ability to ensure equivalent levels of durability and crashworthiness. As the industry gains experience with these materials, these concerns will inevitably diminish, but may remain relevant during the timeframe of this final rulemaking.

In practice, material substitution tends to be quite specific to the manufacturer and situation. Some materials work better than others for particular vehicle components, and a manufacturer may invest more heavily in adjusting to a particular type of advanced material, thus complicating its ability to consider others. The agencies recognize that like any type of mass reduction, material substitution has to be conducted not only with consideration to maintaining equivalent component strength, but also to maintaining all the other attributes of that component, system or vehicle, such as crashworthiness, durability, and NVH.

If vehicle mass is reduced sufficiently through application of the two primary strategies of using less material and material substitution described above, secondary mass reduction options may become available. Secondary mass reduction is enabled when the load requirements of a component are reduced as a result of primary mass reduction. If the primary mass reduction reaches a sufficient level, a manufacturer may use a smaller, lighter, and potentially more efficient powertrain while maintaining vehicle acceleration performance. If a powertrain is downsized, approximately half of the mass reduction may be attributed to the reduced torque requirement which results from the lower vehicle mass. The lower torque requirement enables a reduction in engine displacement, changes to transmission including the torque converter and gear ratios, and changes to final drive gear ratio. The reduced powertrain torque enables the downsizing and/or mass reduction of powertrain components and accompanying reduced rotating mass (*e.g.*, for transmission, driveshafts/halfshafts, wheels, and tires) without sacrificing powertrain durability. Likewise, the combined mass reductions of the engine, drivetrain, and body in turn reduce stresses on the suspension components, steering components, wheels, tires, and brakes, which can allow further reductions in the mass of these subsystems. Reducing the unsprung masses such as the brakes, control arms, wheels, and tires further reduce stresses in the suspension mounting points, which will allow for further optimization and potential mass reduction.

Secondary mass reduction can occur for each kg of primary mass reduction, when all subsystems are redesigned to take the initial primary mass reduction into account. In the MYs 2012-2016 rulemaking analysis, the agencies assumed that 1 kg of primary mass reduction could enable up to 1.25 kg of secondary mass reduction. In the two most recent mass reduction projects by EPA and NHTSA, every 1 kg of primary mass reduction enabled 0.7 kg of secondary mass reduction. We note that these estimates may not be applicable in all real-world instances of mass reduction, and that the literature indicates that the amount of secondary mass reduction potentially available varies significantly from an additional 0.5 kg to 1.25 kg per 1 kg of primary mass reduction, depending on assumptions such as which components or systems primary mass reduction is applied to, and whether the powertrain is available for downsizing. [94,95,96] The amount of secondary mass reduction is also affected by the degree of component sharing that occurs among a manufacturer's models. Component sharing is used by manufacturers to achieve production economies of scale that affect cost and the number of unique parts that must be managed in production and for service. In addition, the engineering resources and capital for tooling and equipment that would be needed to optimize every vehicle component at each redesign affects the ability to fully optimize a new vehicle to achieve all of the theoretically possible secondary mass reduction. While there is agreement in the literature that primary mass reduction can enable secondary mass reduction, the agencies recognize that care must be taken when reviewing reports on mass reduction methods and practices to ascertain the manner and extent to which compounding effects have been considered.

All manufacturers are using some or all of these methods to reduce mass in the vehicles they are producing today, and the agencies expect that the industry will continue to learn and improve the application of these techniques for more vehicles during the rulemaking timeframe. We consider mass reduction in net percentage terms in our analysis not only because effectively determining specific appropriate mass reduction methods for each vehicle in the baseline fleet is a large task beyond the scope of this rulemaking, but also because we recognize that even as manufacturers reduce mass to make vehicles more efficient, they may also be adding mass in the form of increased vehicle features and safety content in response to market forces and other governmental regulations. For these reasons, when the agencies discuss the amount of mass reduction that we are assuming is feasible for purposes of our analysis, we are implicitly balancing both the considerable opportunities that we believe exist for mass reduction in the future, and the reality that vehicle manufacturing is complex and that mass reduction methods must be applied thoughtfully and judiciously as safety and content demands on vehicles continue to increase over time. Despite our considerable discussion of the topic, the agencies' application of mass reduction in our analysis is fairly simplified. As applied in our models, the percentage reduction for a given vehicle that is assumed for a given year is an abstraction of all the specific mass reduction methods described above.

How much mass reduction do the agencies believe is feasible in the rulemaking timeframe?

Feasibility, if narrowly defined as the ability to reduce mass without any constraints, is nearly unbounded. However, in practice, the feasible amount of mass reduction is affected by other considerations. Cost effectiveness is one of those constraints and is discussed further below in the mass reduction cost section. In the analysis for the current rulemaking for MYs 2017-2025, the agencies reviewed a number of public reports and accompanying data, as well as confidential information from manufacturers, and believe that mass reduction of up to 20 percent from a MY 2008 baseline vehicle can be achieved in a cost effective manner using technologies currently in production. More detail on studies reviewed by the agencies and additional studies currently in progress by the agencies is located below in Table 3-9 and in the paragraphs below under the question "***What additional studies are the agencies conducting to inform our estimates of mass reduction amounts, cost, and effectiveness?***"

From a general planning perspective, nearly all automakers have made some public statement regarding vehicle mass reduction being a core part of the overall technology strategy that they will utilize to achieve future fuel economy and CO_2 emission standards.

- Estimates from Ducker Worldwide indicate that the automobile industry will see an annual increase in AHSS of about 10% through 2020[97].
- Ford has stated that it intends to reduce the weight of its vehicles by 250-750 lb per model from 2011 to 2020[98]. For context, the midpoint of that range of reductions would correspond to a 12% reduction from the current Ford new light duty vehicle sales fleet.
- Mazda has released a statement about achieving a 220-lb reduction per vehicle by 2016[99]. This is equivalent to about a 6% reduction for the company's current fleet.
- Land Rover executives have stated that the company remains committed to a goal of reducing curb weights of its SUVs by as much as 500 kilograms over the next 10 years[100].
- In its comment to the NPRM, Volkswagen stated that they expect to reduce the mass of their vehicles by 7-10% on average during the period of this regulation.

Several reports focusing on the OEM's approaches for light weighting are summarized in the University of California Davis study as shown in Table 3-126 [101].

Table 3-126 Automaker industry statements regarding plans for vehicle mass-reduction technology

Affiliation	Quote	Source
General Motors	"We use a lot of aluminum today – about 300 pounds per vehicle - and are likely to use more lightweight materials in the future"	Keith, 2010
Ford	"The use of advanced materials such as magnesium, aluminum and ultra high-strength boron steel offers automakers structural strength at a reduced weight to help improve fuel economy and meet safety and durability requirements"	BMW and SGL, 2010
Nissan	"We are working to reduce the thickness of steel sheet by enhancing the stregnth, expanding the use of aluminum and other lightweight materials, and reducing vehicle weight by rationalizing vehicle body structure"	Goede et al, 2009
BMW	"Lightweight construction is a core aspect for sustainable mobility improving both fuel consumption and CO2 emissions, two key elements of our Efficient Dynamics strategy … we will be able to produce carbon fiber components in large volumes at competitive costs for the first time. This is particularly relevant for electric-powered vehicles."	Nunez, 2009
Volkswagen	"Material design and manufacturing technologies remain key technologies in vehicle development. Only integrated approaches that work on these three key technologies will be successful in the future. In addition to the development of metals and light metals, the research on fibre-reinforced plastics will play a major role."	Goede et al, 2009
Fiat	"A reduction of fuel consumption attains big importance because of the possible economical savings. In order to achieve that, different ways are followed: alternative engine concepts (for example electric engines instead of combustion ones) or weight reduction of the vehicle structure. Using lightweight materials and different joining techniques hleps to reach this aim"	Nunez, 2009
Volkswagen	"Lightweight design is a key measure for reducing vehicle fuel consumption along with powertrain efficiency, aerodynamics and electrical power management"	Krinke, 2009
BMW	"A dynamic vehicle with a low fuel consumption finally demands a stiff body with a low weight. To achieve the initially mentioned targets, it is therefore necessary to design a body which offers good stiffness values and a high level of passive safety at a low weight."	Prestorf, 2009
BMW	"Light weight design can be achieved by engineering light weight, manufacutring light weight and material light weight design."	Prestorf, 2009

Although the focus on mass reduction by manufacturers is widespread, the agencies believe the practical limits of mass reduction will be different for each vehicle model as each model starts with a different mix of conventional and advanced materials, components, and features intended to meet the function and price of a particular market segment. A vehicle that already has a significant fraction of advanced high strength steel (AHSS) or any other advanced material in its structure, for example, will not have the opportunity to realize the same percentage of mass reduction as a vehicle of more traditional construction. Given the myriad methods of achieving mass reduction, and the difficulty in obtaining data, accounting for the current level of mass reduction technology for every model in production in a baseline model year would be an impractical task. However, the agencies believe that reducing vehicle weight to reduce fuel consumption has a continuum of solutions and the technologies employed will have levels of effectiveness and feasibility that will vary by manufacturers and by vehicle. In estimating the amount of mass reduction for this analysis, the agencies also consider fleet safety effects for mass reduction. See Section II.G of the preamble for a detailed discussion of the safety considerations in establishing CAFE and GHG standards. In the CAFE and OMEGA analyses, the agencies considered several levels of mass reduction applicable to all of the models in each subclass, as discussed below.

Based on the many aspects of mass reduction (*i.e.*, feasibility, cost and safety), for the final rule, consistent with the proposal, the agencies believe that mass reduction of up to 20 percent is feasible on light trucks, CUVs and minivans, but that less mass reduction should be implemented on other vehicle types to avoid increases in societal fatalities. While the agencies continue to examine mass reduction, we remain alert to safety considerations and seek to ensure that any CAFE and CO_2 standards can be achieved in a safety-neutral or improved manner.

In the CAFE model, NHTSA applied amounts of mass reduction shown in Table 3-127, which was based on the ability to achieve overall fleet fatality estimates of close to zero. The results are described in Preamble Section II.G and Chapter V of NHTSA's RIA. The amount of mass reduction applied in EPA's OMEGA model follows the safety neutral analysis is described in Section II.G of the Preamble with a variety of tables in EPA's RIA (Chapter 3.8.2).

Table 3-127 Maximum Mass Reduction Amount Applied in CAFE Model

Absolute %	Subcompact and Subcompact Perf. PC	Compact and Compact Perf. PC	Midsize PC and Midsize Perf. PC	Large PC and Large Perf. PC	Minivan LT	Small, Midsize and Large LT
MR1*	0.0%	0.0%	1.5%	1.5%	1.5%	1.5%
MR2	0.0%	0.0%	3.5%	7.5%	7.5%	7.5%
MR3	0.0%	0.0%	0.0%	10.0%	10.0%	10.0%
MR4	0.0%	0.0%	0.0%	0.0%	15.0%	15.0%
MR5	0.0%	0.0%	0.0%	0.0%	20.0%	20.0%

Notes:

*MR1-MR5: different levels of mass reduction used in CAFE model

The amounts of mass reduction shown in Table 3-127 are for conventional vehicles. The agencies assume that vehicles with hybrid and electric powertrain are heavier than conventional vehicles because of the mass of battery systems. In comparing anecdotal data for HEVs, EPA and NHTSA assume a slight weight increase of 4-5% for HEVs as compared to baseline non-hybridized vehicles. The added weight of the Li-ion pack, motor and other electric hardware were offset partially by the reduced size of the base engine as stated in TSD section 3.4.3.8. We believe that this assumption accurately reflects real-world HEV, PHEV and EV construction. As an example, for a subcompact PHEV with 20 mile range operating on electricity, the agencies assume that to achieve no change in total vehicle mass, it would be necessary to reduce the mass of the glider by 6 percent because of the additional weight of the electrification system. The mass reduction for P/H/EVs can be found section 3.3.3.9 in the joint TSD, and in EPA's RIA Chapter 1 and Chapter V, section E.3.h.4, of NHTSA's FRIA.

How much do the agencies estimate mass reduction will cost in the rulemaking timeframe?

Automakers are currently utilizing various mass reduction techniques across the light-duty vehicle fleet, and will continue to use and in some cases expand these approaches for the

2017 to 2025 time frame. These approaches may include optimized design, geometry, part consolidations, and materials substitution. Unlike the other technologies described in this chapter, mass reduction is potentially more complex in that we cannot define it as a single piece of equipment or hardware change to implement the technological improvement. Mass reduction, depending upon the level of reduction targeted, has the potential to impact nearly every system on the vehicle. Because of this complexity, there are unique challenges to estimating the cost for mass reduction and for demonstrating the feasibility of reducing vehicle mass by a given amount. This section describes the cost estimates used for the agencies' analysis.

In the analysis for the MYs 2012-2016 rulemaking, the agencies assumed a constant cost for mass reduction of $1.32 for each pound reduced up to a mass reduction level of 10 percent (or $1.48/lb using an ICM factor of 1.1 for a low-complexity technology). The $1.32/lb estimate was based on averaging three studies: the 2002 NAS Report, a 2008 study by Sierra Research, and a 2007 study by MIT researchers.[eee]

Since the MYs 2012-2016 final rule, the agencies have given further consideration to the cost of mass reduction, and now believe that a cost that varies with the level of mass reduction provides a better estimate. The agencies believe that as the vehicle fleet progresses from lower to higher levels of mass reduction and becomes increasingly optimized for mass and other attributes, the cost for mass reduction will progressively increase. The higher levels of mass reduction may, for example, require applying more advanced materials and technologies than lower levels of mass reduction, which means that the cost of achieving those higher levels may increase accordingly. The unit cost of mass reduction versus the amount of mass reduction might be linear, parabolic, or some other higher order relationship. In the 2017-2025 Notice of Intent, 75 FR 62739 (Oct. 13, 2010), CARB, EPA and NHTSA derived a second order curve based on a study with two vehicle redesigns conducted by Lotus Engineering completed in 2010, such that zero mass reduction had zero cost, and the dollars per pound increased with greater levels of mass reduction. Since the publication of the TAR, the agencies have identified a number of additional studies in the literature relating to the costs of vehicle mass reduction, which are discussed below. The studies show that for low or high mass reduction, the costs can range from small cost savings to significant cost increases. The economic costs associated with mass reduction are difficult to determine conclusively due to the broad range of methods employed to achieve mass reduction. The costs on a specific vehicle or component depend on many factors, such as the design, materials selected, raw material price, appropriate manufacturing processes, production volume, component functionality, required engineering and development, etc.

[eee] Specifically, the 2002 NAS Report estimated that vehicle weight could be reduced by 5 percent (without engine downsizing) at a cost of $210-$350, which translates into $1.50/lb assuming a 3,800 lb base vehicle and using the midpoint cost; Sierra Research estimated that a 10 percent reduction (with compounding) could be accomplished for $1.01/lb, and MIT researchers estimated that a 14 percent reduction (with no compounding) could be accomplished for $1.36/lb. References for these studies are available in endnotes to Chapter 3 of the TSD for the MYs 2012-2016 final rule.

Cost data thus varies widely in the literature. Of the various studies reviewed by the agencies, not all are equal in their original intent, rigor, transparency, or applicability to this regulatory purpose. The individual studies range from complete vehicle redesign to advanced optimization of individual components, and were conducted by researchers with a wide range of experience and background. Some of the studies were literature reviews, while others developed new designs for lighter components or complete lighter vehicles, while yet others built physical components or systems, and conducted testing on those components and systems. Some of the studies focused only on a certain sub-system (which is a building block for the overall vehicle design), while some of them took a systematical approach and re-designed the whole vehicle to achieve the maximum mass reduction and cost reduction. The latter studies typically identified a specific baseline vehicle, and then utilized different engineering approaches and investigated a variety of mass-reduction concepts that could be applied to that vehicle. Some of the differences between studies emanate from the characteristics of the baseline vehicle and its adaptability to the new technology or method, and the cost assumptions relating to the original components and the redesigned components. Assumptions regarding the degree and cost of any associated mass de-compounding can also confound comparisons.[fff] Despite this variation in the literature, in actual practice, we believe manufacturers will choose a target mass reduction for a whole vehicle and for each sub-system, and work to find the lowest total cost method to achieve those targets. Such a process would consider numerous primary and secondary cost factors (including engineering, facilities, equipment, tooling, and retraining costs) as well as technological and manufacturing risks.[ggg]

Regardless of the confidence in specific estimates, the agencies must select a curve that will be applied to the whole fleet that will define the average cost per kg of mass reduction as a function of total percentage of mass reduction. There are many significant challenges that make it difficult for the agencies to establish an estimated cost curve based on the literature, such as the differences in the baselines used in the studies, whether the studies considered platform sharing and powertrain sharing, and other considerations.

[fff] The concept of secondary weight savings or mass compounding (also called mass decompounding) derives from the qualitative understanding that as vehicle weight decreases, other vehicle systems can also decrease in mass while maintaining the original vehicle level of performance and function. For instance, following a primary weight reduction in the vehicle (e.g. Body in White), the designs of some of the other dependant vehicle subsystems (tires, suspensions, brakes, powertrain, body structure) may be redesigned and reduced in mass to account for the overall lighter vehicle. The lighter vehicle is also associated with lighter loads, less friction and drag, and may require less power to be accelerated, and the powertrain may therefore be scaled down in size with a potential for reduced mass, even while maintaining equivalent acceleration performance and functionality. The compounded or secondary mass savings from these additional systems may then drive further mass reductions in the original primary weight reduction (e.g. Body in White). Mass compounding factors found in literature are rough estimates of the secondary mass reduction amount.

[ggg] We also note that the cost of mass reduction in the CAFE model is quantified on a per pound basis that is a function of the percentage decrease in vehicle mass. We assume that OEMs would find the most cost-effective approach to achieve such a mass reduction. Realistically, this would depend heavily on the baseline vehicle as well as the size and adaptability of the initial design to the new technology. Thus, the CAFE model strives to be realistic in the aggregate while recognizing that the figures proposed for any specific model may be debatable.

The costs for mass reduction employed for the main analysis for this final rule are the same as those in the NPRM. The agencies considered updating cost estimates based on the studies that were underway when the NPRM was issued. Those studies included the EPA/ICCT funded Phase 2 Toyota Venza Low Development project and the NHTSA funded Honda Accord mass reduction project, which are described in the section titled "*What additional studies are the agencies conducting to inform our estimates of mass reduction amounts, cost, and effectiveness?"* However, these studies were in the middle of the peer review process and had not yet been finalized at the time when the inputs for the main analysis for this final rule were required. For the final rule, the agencies decided to continue to use the same costs for mass reduction that were used in the NRPM.

The agencies examined all the studies in Table 3-128 including information supplied by manufacturers (during meetings held subsequent to the TAR) when deciding the mass reduction cost estimate used for the proposal, which has been carried forward for this FRM.[hhh] The agencies considered three major factors in examining these studies. First, whether a study was rigorous in terms of how it evaluates and validates mass reduction from technological and design perspectives. This includes consideration of a study's comprehensiveness, the technical rigor of its methodology, the validation methods employed, and the relevance of the technologies evaluated in the study given our rulemaking time frame. Second, whether a study was rigorous in terms of its estimation of costs, including the completeness and rigor of the methodology, such as whether the study includes data for all categories of direct manufacturing costs, and whether the study presents detailed cost information for both the baseline and the light-weighted design. And third, the degree of peer review, including if the study is peer-reviewed, and whether it has effectively addressed any critical technical, methodological, and cost issues raised by the peer-review, if this information is available.

Some of the variation may be attributed to the complexity of mass reduction as it is not one single discrete technology and can have direct as well as indirect effects on other systems and components. The 2011 NAS study speaks to this point when it states on page 7-1 that "[t]he term material substitution oversimplifies the complexity of introducing advanced materials, because seldom does one part change without changing others around it." These variations underscore that there is not a unique mass reduction solution as there are many different methods with varying costs for taking mass out of vehicles, and every manufacturer, even every vehicle, could have a different approach depending on the specific vehicle, assembly plant and model year of implementation. The agencies recognize that there are challenges to characterizing the mass reduction plans for the entire future fleet due to the complexity and variety of methods available. So far the agencies have not found any study that addresses how to generalize the mass reduction that is achievable on a single vehicle to

[hhh] The agencies considered confidential cost information provided by OEMs that covered a range of components, systems, designs and materials. Some of these cost estimates are higher than some of the literature studies, and manufacturers provided varying levels of detail on the basis for the costs such as whether mass compounding is included, or whether the costs include markup factors.

the whole fleet. Table 3-128 contains a summary of the data contained in the studies, and the OEM CBI data, which the agencies reviewed. There is a degree of uncertainty associated with comparing the costs from the range of studies in the literature when trying to summarize them in a single table, and we encourage interested stakeholders to carefully review the information in the literature. For some of the cost estimates presented in the papers there are unknowns such as: what year the costs are estimated for, whether mass decompounding (and potential resultant cost savings) was taken into account, and whether mark-ups or indirect costs were included. The agencies tried to normalize the cost estimations from all these studies by converting them to 2009 year dollar, applying mass compounding factor of 1.35 for mass reduction amount more than 10 percent if it has not been applied in the study and factoring out the RPE specified in the study to derive direct manufacture costs for comparison. There are some papers that give cost for only component mass reduction, others that have more general subsystem costs and others yet that estimate total vehicle mass reduction costs (which often include and present data at the subsystem level). Other studies have multiple scenarios for different materials, different vehicle structures and mass reduction strategies. Thus, a single study which contains more than one vehicle can be broken down into a range of vehicle types, or at the subsystem level, or even at the component level. While Table 3-128 is inclusive of all of the information reviewed by the agencies for the NPRM, for the reasons described above the technical staff for the two agencies applied various approaches in evaluating the information. The linear mass-cost relationship developed for the proposal is carried forward to this final rule and presented below is the consensus assessment from the two agencies of the appropriate mass cost for this final rule.

Table 3-128 Mass Reduction Studies Considered for Estimating Mass Reduction Cost for this FRM studies

		Cost Information from Studies									
	Cost Year	Mass Reduction [lb]	Compounding Factor	Mass Reduction with Compounding [lb]	Baseline Vehicle Weight [lb]	Mass Reductioning w/Compounding [%]	Cost [$]	RPE	Dollar Multiplier to 2009	2009 Direct Manufacturing Cost [$]	Unit Cost of Mass Reduction [$/lb]
Individual Cost Data Points											
AISI, 1998 (ULSAB)	1998	103	1	103	2977	3.5%	-$32	1.0	1.28	-$41	-$0.40
AISI, 2000 (ULSAC)	2000	6	1	6	2977	0.2%	$15	1.0	1.24	$18	$2.99
Austin et al, 2008 (Sierra Research) - ULS Unibody	2008	320	1	320	3200	10.0%	$209	1.61	1.01	$131	$0.41
Austin et al, 2008 (Sierra Research) - AL Unibody	2008	573	1	573	3200	17.9%	$1,805	1.61	1.01	$1,134	$1.98
Austin et al, 2008 (Sierra Research) - ULS BoF	2008	176	1	176	4500	3.9%	$171	1.61	1.01	$107	$0.61
Austin et al, 2008 (Sierra Research) - AL BoF	2008	298	1	298	4500	6.6%	$1,411	1.61	1.01	$887	$2.98
Bull et al, 2008 (Alum Assoc.) - AL BIW	2008	279	1	279	3378	8.3%	$455	1.0	1.01	$460	$1.65
Bull et al, 2008 (Alum Assoc.) - AL Closure	2008	70	1	70	3378	2.1%	$151	1.0	1.01	$153	$2.17
Bull et al, 2008 (Alum Assoc.) - Whole Vehicle	2008	573	1	573	3378	17.0%	$122	1.0	1.03	$126	$0.22

Cheah et al, 2007 (MIT) - 20%	2007	712	1	712	3560	20.0%	$646	1.0	1.03	$667	$0.94
Das, 2008 (ORNL) - AL Body & Panel	2008	637	1	637	3363	19.0%	$180	1.5	1.01	$121	$0.19
Das, 2008 (ORNL) – FRPMC	2008	536	1.0	536	3363	15.9%	-$280	1.5	1.01	-$189	-$0.35
Das, 2009 (ORNL) - CF Body & Panel, AL Chassis	2009	933	1	933	3363	27.7%	$1,490	1.5	1.00	$993	$1.06
Das, 2010 (ORNL) - CF Body & Panel, Mg Chassis	2010	1173	1	1173	3363	34.9%	$373	1.5	1.00	$248	$0.21
EEA, 2007 - Midsize Car - Adv Steel	2007	236	1	236	3350	7.0%	$179	1.0	1.03	$185	$0.78
EEA, 2007 - Midsize Car - Plast/Comp	2007	254	1	254	3350	7.6%	$239	1.0	1.03	$247	$0.97
EEA, 2007 - Midsize Car – Al	2007	586	1.35	791	3350	23.6%	$1,388	1.0	1.03	$1,434	$1.81
EEA, 2007 - Midsize Car – Mg	2007	712	1.35	961	3350	28.7%	$1,508	1.0	1.03	$1,558	$1.62
EEA, 2007 - Light Truck - Adv Steel	2007	422	1	422	4750	8.9%	$291	1.0	1.03	$301	$0.71
EEA, 2007 - Light Truck - Plast/Comp	2007	456	1	456	4750	9.6%	$398	1.0	1.03	$411	$0.90
EEA, 2007 - Light Truck - Al	2007	873	1.35	1179	4750	24.8%	$1,830	1.0	1.03	$1,891	$1.60
EEA, 2007 - Light Truck - Mg	2007	1026	1.35	1385	4750	29.2%	$1,976	1.0	1.03	$2,042	$1.47
Geck et al, 2008 (Ford)	2008	1310	1	1310	5250	25.0%	$500	1.0	1.01	$506	$0.39
Lotus, 2010 – LD	2010	660	1	660	3740	17.6%	-$121	1.0	1.00	-$120	-$0.18
Lotus, 2010 – HD	2010	1217	1	1217	3740	32.5%	$362	1.0	1.00	$360	$0.30
Montalbo et al, 2008 (GM/MIT) - Closure - HSS	2008	25	1	25	4000	0.6%	$10	1.0	1.01	$10	$0.41
Montalbo et al, 2008 (GM/MIT) - Closure - AL	2008	120	1	120	4000	3.0%	$110	1.0	1.01	$111	$0.92
Montalbo et al, 2008 (GM/MIT) - Closure - Mg/AL	2008	139	1	139	4000	3.5%	$110	1.0	1.01	$111	$0.80
Plotkin et al, 2009 (Argonne)	2009	683	1	683	3250	21.0%	$1,300	1.0	1.00	$1,300	$1.90

(… Continued) Mass Reduction Studies Considered for Estimating Mass Reduction Cost for this FRM

Studies		Cost Information from Studies									
	Cost Year	Mass Reduction [lb]	Compounding Factor	Mass Reduction with Compounding [lb]	Baseline Vehicle Weight [lb]	Mass Reductioning w/Compounding [%]	Cost [$]	RPE	Dollar Multiplier to 2009	2009 Direct Manufacturing Cost [$]	Unit Cost of Mass Reduction [$/lb]
Cost Curves											
NAS, 2010	2010					1.0%					$ 1.41
	2010					2.0%					$ 1.46
	2010					5.0%					$ 1.65
	2010					10.0%					$ 1.52
	2010					20.0%					$ 1.88

OEM1	2010					8.0%					$ 6.00
	2010					9.0%					$ 7.00
	2010					9.5%					$ 8.00
	2010					10.0%					$ 12.00
	2010					11.0%					$ 25.00
OEM2	2010					0.4%					$ -
	2010					0.9%					$ 0.10
	2010					1.9%					$ 0.20
	2010					2.3%					$ 0.33
	2010					2.4%					$ 0.38
	2010					3.1%					$ 0.60
	2010					3.6%					$ 0.76
	2010					4.0%					$ 0.85
	2010					4.1%					$ 0.88
	2010					4.5%					$ 0.98
	2010					4.8%					$ 1.09
	2010					5.0%					$ 1.17
OEM3	2010					4.0%					$ 0.57
	2010					7.5%					$ 1.01
	2010					10.0%					$ 1.51
OEM4	2011					6.9%					$ 0.97
	2011					8.1%					$ 1.02
	2011					16.4%					$ 1.95

EPA and NHTSA scrutinized the various available studies in the literature as well as confidential information provided by several auto firms based on the kinds of factors described above for purposes of estimating the cost of mass-reduction in the 2017-2025 timeframe. We determined that there was wide variation across the studies with respect to costs estimates, applicability to the 2017-2025 time frame, and technical rigor. The mass cost curve that was developed is defined by the following equation and is shown in Figure 3-33:

Mass Reduction Direct Manufacturing Cost (DMC) (\$/lb) = \$4.36/(%-lb) x Percentage of Mass Reduction Level (%) (2010\$)

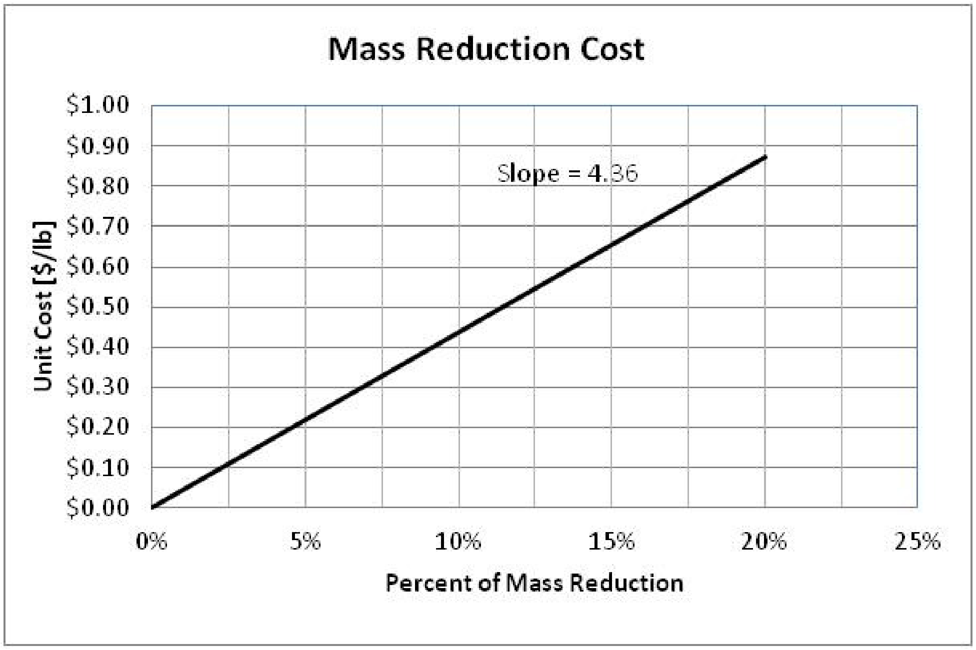


Figure 3-33 NPRM and FRM Mass Reduction Direct Manufacturing Cost

For example, this results in an estimated $175 cost increase for a 10% mass reduction of a 4,000lb vehicle (or $0.44/lb), and a $394 cost increase for 15% reduction on the same vehicle (or $0.66/lb).

As mentioned in the NPRM, due to the wide variation in data used to select this estimated cost curve, the agencies have also conducted cost sensitivity studies in their respective RIAs in both the proposal and final rule using values of +/-40%. The wide variability in the applicability and rigor of the studies also provides justification for continued research in this field.

The agencies consider this DMC to be applicable to the MY2017 and consider mass reduction technology to be on the flat portion of the learning curve in the MY2017-2025 timeframe. To estimate indirect costs for applied mass reduction of up to 15%, the agencies have applied a low complexity ICM of 1.24 through 2018 and 1.19 thereafter. To estimate indirect costs for applied mass reduction of 15% to 25%, the agencies have applied a medium complexity ICM of 1.39 through 2024 and 1.29 thereafter. To estimate indirect costs for applied mass reduction greater than 25%, the agencies believe it is appropriate to apply a high1 complexity ICM of 1.56 through 2024 and 1.35 thereafter.

The agencies sought comment in the draft Joint TSD for the NPRM (p. 210) regarding options for realistically and appropriately assessing the degree of feasible mass reduction for vehicles in the rulemaking timeframe and the total costs to achieve that mass reduction, but got no specific response. The agencies also sought comments on what practical limiting factors need to be considered when considering maximum feasible amount of mass reduction; the degree to which these limiting factors will impact the amount of feasible mass reduction (in terms of the percent of mass reduction); the best method(s) to assess an appropriate and feasible fleet-wide amount mass reduction amount (because each study mainly focuses on a single vehicle); etc. In its comments, VW stated that it "projects full vehicle weight reductions during the time period of this regulation on average in the order of 7-10%." VW noted that this was lower than the agencies' estimates in the NPRM of upwards of 20% mass reduction for large cars and some trucks, which VW stated may exceed cost effective limits. As stated later in this section, the detailed studies sponsored by the agencies suggest that 20% mass reduction is likely feasible for the rulemaking period without using exotic materials or highly advanced technologies. The accompanying detailed cost analysis indicates that the cost of reducing mass by 20% can potentially be economical. The agencies also noted in the NPRM that we expected to refine our estimate of both the amount and the cost of mass reduction between the NPRM and the final rule based on the agencies' ongoing work described a later section, below. As stated before, due to the limited time and the extensive scope of these studies, the agencies did not finish them in time for inclusion in the final rule analysis.

How effective do the agencies estimate that mass reduction will be?

A rule of thumb used by researchers and industry, based on testing and simulation, is that 10 percent reduction in vehicle mass can be expected to generate a 6 to 8 percent increase in fuel economy if the vehicle powertrain and other components are also downsized accordingly.[102] In the analysis for the MYs 2012-2016 final rule, NHTSA and EPA estimated that a 10 percent mass reduction with engine downsizing would result in a 6.5 percent reduction in fuel consumption while maintaining equivalent vehicle performance (*i.e.*, 0-60 mph time, towing capacity, etc.), consistent with estimates in the 2002 NAS report. For small amounts of mass reduction, such as the 1.5 percent used at vehicle refresh in NHTSA's modeling, no engine downsizing was used, so a 10 percent mass reduction without engine downsizing was assumed to result in a 3.5 percent reduction in fuel consumption. In this FRM, both agencies have chosen to use the effectiveness value for mass reduction from EPA's lumped parameter model to maintain consistency. EPA's lumped parameter model-estimated mass reduction effectiveness is based on a simulation model developed by Ricardo, Inc. under contract to EPA. The 2011 Ricardo simulation results show an effectiveness of 5.1 percent for every 10 percent reduction in mass. NHTSA has assumed that for mass reduction amounts less than 10 percent, the effectiveness is 3.5 percent. For mass reduction greater than 10 percent, NHTSA estimates the effectiveness is 5.1 percent in order to avoid double counting benefits – because the effectiveness of engine downsizing is included in the effectiveness of the engine decision tree when applying engine downsizing, it should appropriately be removed from the mass reduction effectiveness value in the mass reduction decision tree. EPA applies an effectiveness of 5.1 percent for every 10 percent mass reduction, and this scales linearly from 0 percent mass reduction, up to the maximum applied mass reduction for any given vehicle, which in this final rule is never larger than 20 percent.

What additional studies are the agencies conducting to inform our estimates of mass reduction amounts, cost, and effectiveness?

In the MYs 2012-2016 final rule, the agencies stated that there are several areas concerning vehicle mass reduction and vehicle safety on which the agencies would focus their research efforts and undertake further study. The following vehicle level projects focus on the goals stated in the MYs 2012-2016 final rule, which include determining the maximum potential for mass reduction in the MY 2017-2025 timeframe by using advanced materials and improved designs while continuing to meeting safety regulations and voluntary guidelines and while maintaining all aspects of vehicle functionality. The fourth study investigates the effects of resultant study designs on fleet safety by evaluating crash performance with objects and other vehicles of different size and mass.

1. NHTSA sponsored mass reduction study on a Honda Accord
2. EPA sponsored mass reduction study on a Toyota Venza (Phase 2 Low Development)
3. California Air Resources Board mass reduction study on a Toyota Venza (Phase 2 High Development)
4. NHTSA fleet-wide simulation study - crash analysis using the resultant designs from the studies 1-3 with objects and the design models of other vehicles with different size and mass.

Due to the extensive scope of work for these studies and tight time schedule, some of the studies were finished, but peer reviews and response to peer reviews were not completed in time to enable the results to inform the final rule. We note, however, that the intermediate results from the mass reduction studies would corroborate the level of feasible amount of mass reduction the agencies chose to apply in the NPRM and FRM analyses. Rulemaking modeling results show that the costs for mass reduction are not sensitive to the cost curve of the rulemaking. In the NPRM, EPA found that a +/- 40% change in the cost of mass reduction had very little impact on the cost of the program. This is largely because of safety restraints imposed in the amount of mass reduction selected for the various vehicle classes primarily drive the penetration rates of the technology, rather than the relative cost-effectiveness of the technology itself.

The following sections describe the status and results of the studies sponsored by the agencies.

NHTSA Sponsored Mass Reduction Study

BACKGROUND: NHTSA awarded a contract in December 2010 to Electricore, with EDAG and George Washington University (GWU) as subcontractors, to study the maximum feasible amount of mass reduction for a mid-size car – specifically, a Honda Accord - while keeping the vehicle functionality the same as the baseline vehicle. The Electricore/EDAG/GWU project team was charged with maximizing the amount of mass reduction using technologies that are considered feasible for production of 200,000 units per year during the time frame of this rulemaking while maintaining retail price in parity (within ±10%) with the baseline vehicle. In addition, all designs, materials, technologies and manufacturing processes must be realistically projected to be feasible for industry-wide application in MYs 2017-2025. The project focused on mass reduction and allowed powertrain downsizing, however alternative powertrains, such as diesels, HEVs and EVs, were not to be considered.

MATERIAL AND TECHNOLOGY SELECTION: For vehicle redesigns, OEMs normally select technologies, materials and manufacturing processes that are currently in use on existing vehicle platforms or planned to be in use on future vehicle platforms. The use of the same or similar technologies, materials and manufacturing processes helps maintain or improve component and vehicle reliability, manufacturability and cost. New materials, technologies and processes are often introduced in low-volume, high price vehicles first and then migrate to high production volume vehicle lines over time. This significantly reduces the risk to OEMs associated with implementing new technologies. Recognizing this when selecting materials, technologies and manufacturing processes, the Electricore/EDAG/GWU team utilized, to the extent possible, only those materials, technologies and design which are currently used or planned to be introduced in the near term (MY 2012-2015) on low-volume production vehicles. The recommended materials (Advanced High Strength Steels, Aluminum, Magnesium and Plastics) manufacturing processes (Stamping, Hot Stamping, Die Casting, Extrusions, Roll Forming) and assembly methods (Spot welding, Laser welding and Adhesive Bonding) are at present used, some to a lesser degree than others. These technologies can be fully developed within the normal product design cycle using the current design and development methods. The process parameters for manufacturing with Advanced High Strength Steels can be supported by computer simulation. This approach minimized those material and technology options which would likely be overly aggressive or unrealistic to implement in mass production in model years 2017-2025.

ENGINEERING APPROACH: The Electricore/EDAG/GWU team took a "clean sheet of paper" approach and adopted collaborative design, engineering and CAE process with built-in feedback loops to incorporate results and outcomes from each of the design steps into the overall vehicle design and analysis. The team torn down and benchmarked 2011 Honda Accord and then undertook a series of baseline, noting the designs, materials, technologies and overall design optimization level of the baseline vehicle. Vehicle performance, safety simulation and cost analyses were run in parallel to the design study to help ensure that the design decisions for the concept vehicle would be informed by a well-documented baseline, thus enabling the resultant design to meet the defined project criteria.

While working within the constraint of maintaining the baseline Honda Accord's exterior size and shape, the body structure was first redesigned using topology optimization with six load cases including bending stiffness, torsion stiffness, IIHS frontal impact, IIHS side impact, FMVSS pole impact, FMVSS rear impact and FMVSS roof crush cases. The load paths from topology optimization were analyzed and interpreted by technical experts and the results were then fed into low fidelity 3G (Gauge, Grade and Geometry) optimization programs to further optimize for material properties, material thicknesses and cross-sectional shapes while trying to achieve the maximum amount of mass reduction. The Electricore/EDAG/GWU team carefully reviewed the optimization results and built detailed CAD/CAE models for the body structure, closures, bumpers, suspension, and instrumentation panel. The vehicle designs were also carefully reviewed by manufacturing technical experts to ensure that they could be manufactured at high volume production rates. Detailed manufacturing layouts were created and were later used to estimate costs.

Multiple materials were used for this study. The body structure was redesigned using a significant amount of advanced high strength steel (AHSS). The closure and suspension were designed using a significant amount of aluminum. Magnesium was used for the instrumentation cross-car beam. A limited amount of composite material was used for the seat structure. Electricore and its sub-contractors consulted industry leaders and experts for each component and sub-system when deciding which mass reduction technologies were feasible.

DESIGN AND FUNCTION VALIDATION: In order to ensure that the light weighted vehicle had the same functionality as the baseline vehicle, Electricore and its sub-contractors used the CAD/CAE/powertrain models and conducted simulation modeling. This is the first mass reduction study that has been released publicly that includes such a broad array of vehicle simulation modeling analyses to assess vehicle functionality and performance relative to these critical attributes. These significant additional analyses provide greater confidence that the designs employed in this study are more feasible for production implementation than a study without these analyses, although the agency notes that significantly more testing and validation work is required to refine and finalize a design for production.

- Safety: Safety performance of the light-weighted design is compared to the safety rating of the baseline MY2011 Honda Accord for seven consumer information and federal safety crash tests using LS-DYNA[iii]. These seven tests are NCAP frontal test, NCAP lateral MDB test, NCAP lateral pole test, IIHS roof crush, IIHS lateral MDB, IIHS front offset test, and FMVSS No. 301 rear impact tests. All tests achieved safety performance equivalent to MY 2011 Honda Accord when comparing crash pulse and passenger compartment intrusion levels, with no damage to the fuel tank. This study does not include restraint systems and dummy which would be part of NHTSA's fleet simulation study.

- Body Stiffness/ Ride and Handling/NVH: Vehicle body torsional and bending stiffness are signatures for the vehicle structure performance. Higher stiffness is generally associated with a refined ride and handling qualities. The baseline vehicle body structure underwent testing for normal modes of vibration, and torsion and bending stiffness. A detailed FEA model of the light-weighted structure was created and analyzed using the MSC/NASTRAN simulation. The torsional stiffness of the light-weighted design is 30% higher than the baseline vehicle while the bending stiffness is 40% higher. The normal mode frequency test results for the light-weighted body structure, which represents vehicle dynamic stiffness, also are within 2.3% of the targets. These stiffness and modes results show that the light-weighted design will have improved ride and handling and improved NVH performance comparing to a vehicle with lower stiffness.

- Vehicle Ride and Handling: In the light-weighted design, the front suspension is redesigned using a MacPherson strut instead of the heavier double wishbone used in

[iii] LS-DYNA is a software developed by Livermore Software Technologies Corporation used widely by industry and researchers to perform highly non-linear transient finite element analysis.

the baseline vehicle. Vehicle ride and handling is evaluated using MSC/ADAMS[jjj] modeling on five maneuvers, fish-hook test, double lane change maneuver, pothole test, 0.7G constant radius turn test and 0.8G forward braking test. The results from the fish-hook test show that the light-weighted vehicle can achieve a five-star rating for rollover, same as baseline vehicle. The double lane change maneuver tests according to the ISO standard show that the chosen suspension geometry and vehicle parameter of the light-weighted design are within acceptable range for safe high speed maneuvers. These simulations are performed to further validate the chosen light weighted front suspension design.

- Durability: There are two types of durability, stress related and corrosion related. Stress related durability for the light-weighted vehicle is evaluated using strain-based analysis based on pot hole, 0.8G forward braking and 0.7G cornering road load cases using ADAMS model. Results from the simulation show that the life of the light-weighted vehicle body structure exceeds the targets. Although timing and funding did not allow corrosion testing to be conducted, the Electricore/EDAG/GWU team considered the properties of materials used, and the location and the functionality of the components to avoid potential issues with corrosion.

- Powertrain Performance: The powertrain of the light-weighted vehicle is downsized from 2.4L naturally aspirated engine to 1.8L naturally aspirated engine to maintain the same vehicle acceleration and towing compared to the baseline 2011 Honda Accord. A powertrain simulation tool PSAT[kkk] is used to verify and validate the light-weighted vehicle for fuel economy and powertrain performance. The light-weighted vehicle with 1.8L NA engine will have 32 mpg fuel economy with comparable 0-30 mph time, 0-60 mph time, quarter mile time, gradability and maximum speed at grade. The only metrics that the light-weighted vehicle performs less than the baseline vehicle is vehicle maximum speed (127 mph for the baseline Accord and 112 mph for the light-weighted design) which the Electricore/EDAG/GWU team and NHTSA believe is acceptable. As a result of the improved fuel economy, the fuel tank for the light-weighted vehicle can be reduced from 18.5 gallon to 15.8 gallon with the same driving range, which further reduced vehicle weight both by reducing fuel tank mass and the mass of fuel carried by the vehicle.

- Manufacturability: The manufacturability of all proposed body structure panels were then assessed using simulation tools, which included HYPER-FORM for stamping parts, and other single step process simulation tools for parts manufactured using other methods, such as hot stamping for B-pillar.

[jjj] MSC/ADAMS: Macneal-Schwendler Corporation/Automatic Dynamic Analysis of Mechanical Systems.
[kkk] PSAT is a plug-and-play architecture software that allows the user to build and evaluate a vehicle's fuel economy and powertrain performance under varying load conditions and drive cycles. It uses MATLAB in a Simulink environment to record data, calculate and input powertrain requirements based on driver demand and current powertrain values. The software is sponsored by the U.S. Department of Energy and developed by Argonne National Laboratory (ANL). http://www.transportation.anl.gov/modeling_simulation/PSAT/index.html

COST ANALYSIS; A detailed cost analysis for the light weighted design and cost estimates for alternative design options were also conducted. For OEM-manufactured parts, a detailed cost model was built based on a Technical Cost Modeling (TCM) approach developed by the Massachusetts Institute of Technology (MIT) Materials Systems Laboratory's research[103] for estimating the manufacturing costs of OEM parts. The costs were broken down into each of the operations involved in the manufacturing, such as for a sheet metal part production by starting from blanking the steel coil, until the final operation to fabricate the component. Total costs were then categorized into fixed cost, such as tooling, equipment, and facilities; and variable costs such as labor, material, energy, and maintenance. These costs were assessed through an interactive process between the product designer, manufacturing engineers and cost analysts. For OEM-purchased parts, the costs were estimated by consultation with experienced cost analysts and Tier 1 suppliers. Forty-one concise spreadsheets are created for both the baseline vehicle and the light-weighted design in the cost model to calculate both the manufacturing and assembly costs.

FINAL RESULTS: To achieve the same vehicle performance as the baseline vehicle, the size of the engine for the light-weighted vehicle was proportionally reduced from 2.4L-177 HP to 1.8L-140HP. Overall the complete light weight vehicle achieved a total weight savings of 22 percent (332kg) relative to the baseline vehicle (1480 kg) at an incremental cost increase of $319 or $0.96 per kg. Without the mass and cost reduction allowance for the powertrain (including engine, transmission, fuel system, exhaust system and fuel) the mass saving for the 'glider' is 24 percent (264 kg) at mass saving cost premium of $1.63 per kg of mass saving. The Electricore/EDAG/GWU team also developed a cost curve to cover a range of mass reduction levels from 0% to 28% for both the full vehicle with engine downsizing and for the glider only. When developing the cost curves, the project team used data that were developed in the study to derive a mass compounding factor (secondary mass reduction/total mass reduction), which was determined to be 0.7. The cost curves are shown in Figure 3-34 and Figure 3-35.

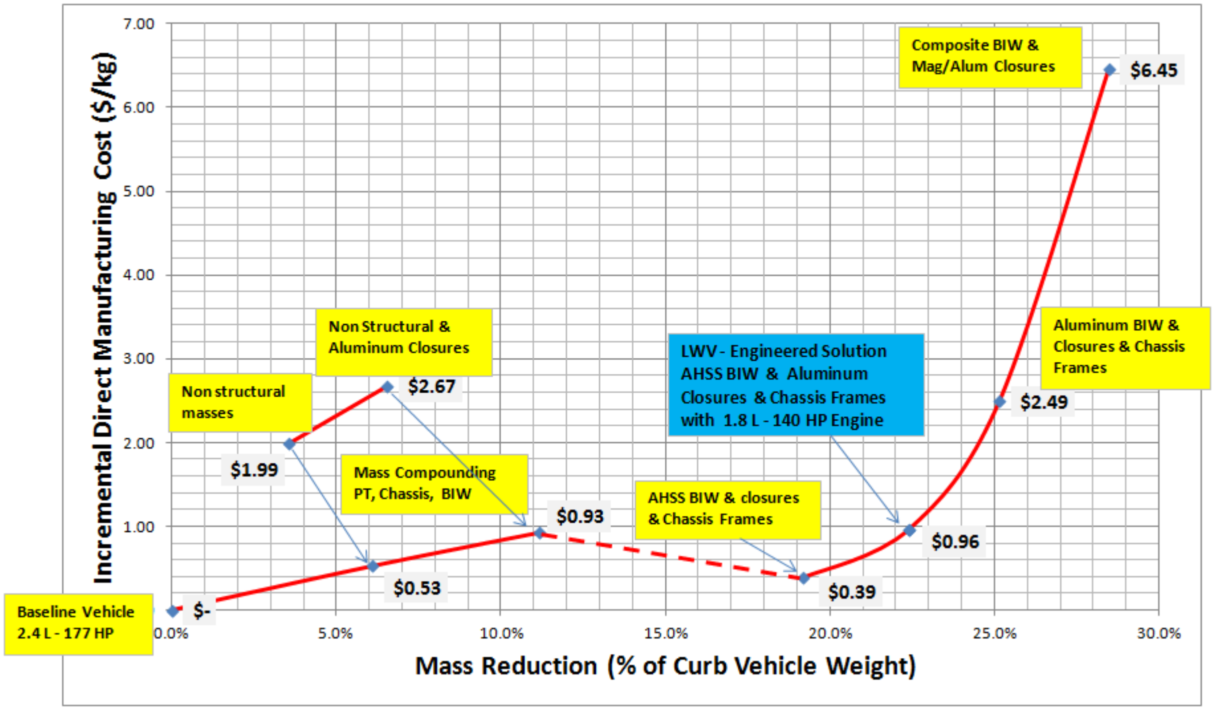


Figure 3-34 Mass Reduction Cost with Allowance for Powertrain Downsizing

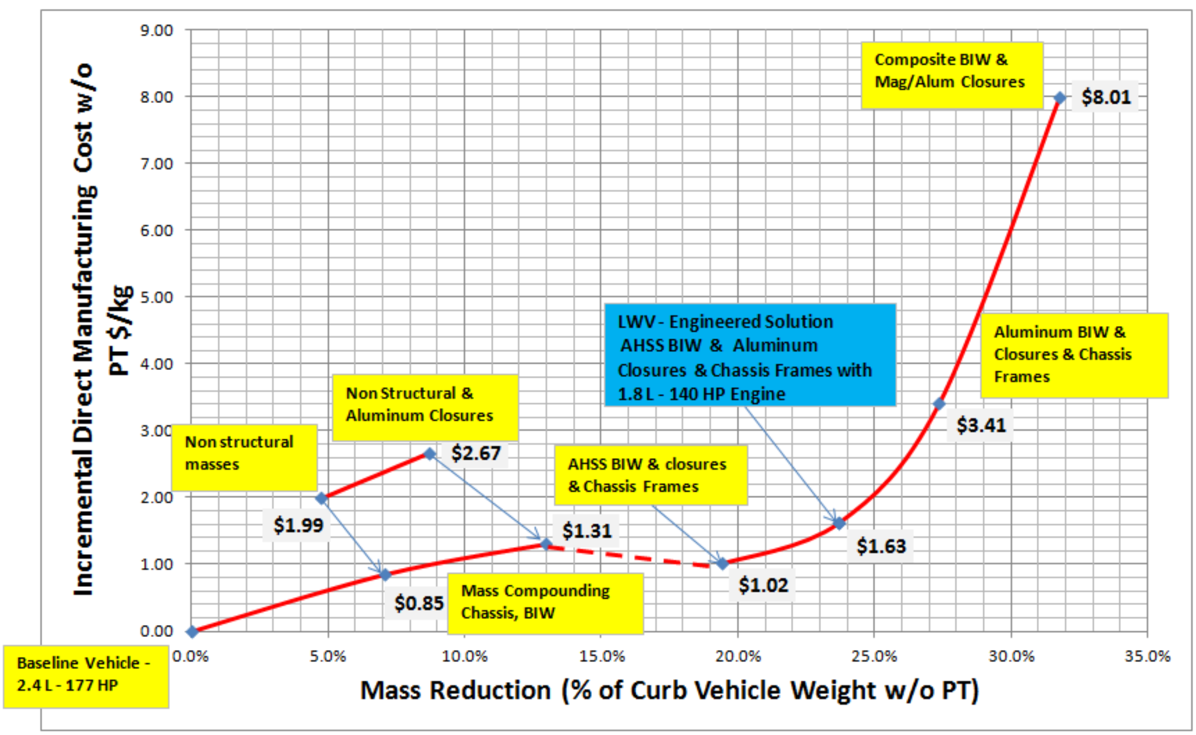


Figure 3-35. Mass Reduction Cost for the Glider Only

PEER REVIEW: The study has been peer reviewed by three technical experts from the industry, academia and a DOE national lab. In the peer reviewer charge letter, the agency asked the peer reviewers to comment on the following five specific items as well as any other potential areas for comments.

- Assumptions and data sources
- Vehicle design and optimization methodology and its rigorousness
- Vehicle functionality and crashworthiness testing methodological rigor
- Vehicle manufacturing cost methodology and its rigorousness
- Conclusions and findings

Comments from peer reviewers were generally positive. The peer reviewers concurred with the methodologies employed in the study and the technologies applied to the light-weighted design, although one peer reviewer commented that not enough composite materials were used in the design. One peer reviewer stated in his comments that "the main findings appear to be based on sound economic and engineering principles." The peer reviewers stated that the cost estimates developed in the study, particularly based on the TCM model, seem to be reasonable, with one peer reviewer commenting the final cost is on the lower side and another commenting it is on the higher side. All three peer reviewers looked into the details of the CAE and cost modeling. One significant concern identified in the peer review was whether the light-weighted vehicle maintained the same performance level in the NCAP side MDB test. In response to that concern, the Electricore/EDAG/GWU team conducted simulation testing and revised the B-pillar design, increasing the gauge for the steel for better performance. Because NCAP only measures injuries to dummies and the crash performance of the light-weighted design is based on the vehicle center of gravity crash pulse level, B-pillar velocity and passenger compartment and intrusion, to assess correlation of the model performance to the baseline vehicle, NHTSA asked a contractor who performs NHTSA's NCAP testing to take additional measurements of the interior intrusion for the 2011 baseline Honda Accord. The updated design and the Honda Accord test data showed similar intrusion results for both NCAP and IIHS side impact tests, and those results support that the light-weighted design could possibly achieve similar NCAP and IIHS ratings, especially when the structure design is fine tuned with the restraint system design which NHTSA will study in the fleet simulation study described later on in this section. For other peer review comments, the Electricore/EDAG/GWU team addressed the comments fully in the report and also composed a response to peer review comment document, which is included at the end of the report. The final report[104], CAE model and cost model, and peer review comments[105] are available in Docket No. NHTSA-2010-0131 and can also be found on NHTSA's website[lll].

EPA Sponsored Mass Reduction Study

EPA, along with ICCT, funded a contract with FEV, with subcontractors EDAG (CAE modeling) and Munro & Associates, Inc. (component technology research) to study the feasibility, safety and cost of 20% mass reduction on a 2017-2020 production ready mid-size crossover utility vehicle (CUV) specifically, a Toyota Venza while maintaining cost parity or reduction. The EPA report is entitled "*Light-Duty Vehicle Mass-Reduction and Cost Analysis – Midsize Crossover Utility Vehicle*".[106] This study is a Phase 2 study of the low development design in the 2010 Lotus Engineering study "An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program"[107], herein described as "Phase 1".

Results for the EPA Phase 2 study of the 1710kg 2010 Toyota Venza include an 18% mass reduction (with powertrain), 312kg, at -$0.43/kg cost (cost savings), including tooling. While the results for $/kg appear similar between the Phase 1 Lotus study (without powertrain, 19% mass reduction, 246kg, at -$0.44/kg), it should be noted that each study took slightly different approaches. The Phase 1 study included mass reduction of every system except the powertrain. The EPA Phase 2 study focused on the vehicle as a whole (including all systems), but also included the powertrain.

LOTUS PHASE 1 STUDY: The original 2009/2010 Phase 1 effort by Lotus Engineering was funded by Energy Foundation and ICCT to generate a technical paper which would identify potential mass reduction opportunities for a selected vehicle representing the crossover utility segment, a 2009 Toyota Venza. Lotus examined mass reduction for two scenarios – a low development (20% MR and 2017 production with technology readiness of 2014) and high development (40% MR and 2020 production with technology readiness of 2017). Lotus disassembled a 2009 Toyota Venza and created a bill of materials (BOM) with all components. Lotus then investigated emerging/current technologies and opportunities for mass reduction. The report included the BOM for full vehicle, systems, sub-systems and components as well as recommendations for next steps. The potential mass reduction for the low development design includes material changes to portions of the body in white (underfloor and body, roof, body side, etc.), seats, console, trim, brakes, etc. The original powertrain was changed to a hybrid configuration. The Phase 1 project achieved 19% (without the powertrain) at 99% of original cost at full phase-in after peer review comments taken into consideration.[mmm] This was calculated to be -$0.45/kg utilizing information from Lotus.

The Lotus Phase 1 study created a good foundation for the next step of analyses of CAE modeling for safety evaluations and in-depth costing (these steps were not within the scope of the Phase 1 study) as noted by the peer reviewer recommendations.[108] The study was peer reviewed. Mr. Sujit Das, of ORNL and an author of several reports on mass reduction, reported that the mass reduction opportunities were reasonable and likely to meet the stated objectives. Mr. Das also recommended using a consistent cost methodology. Dr. Malen, a professor at the University of Michigan, reported the mass reduction opportunities were

[mmm] Cost estimates were given in percentages – no actual cost analysis was presented for it was outside the scope of the study, though costs were estimated by the agency based on the report.

reasonable and likely to meet the stated objectives and also recommended a data driven methodology that can be examined at each step of the analysis.[109]

OBJECTIVES OF EPA PHASE 2 STUDY: The study works to maximize the amount of mass reduction with technologies and techniques that are considered feasible in manufacturability and cost effective for a MY 2017 high volume production vehicle. The EPA Phase 2 study includes the creation of several CAE body in white (BIW) models which could be used to analyze body stiffness, NVH modal characteristics (overall torsion mode, overall lateral bending mode, rear end match boxing mode and overall vertical bending rear end mode in addition to overall and bending and torsional stiffness) and crash (FMVSS and NCAP) performance. The study also includes a rigorous cost analysis including tooling and piece cost. The in-depth cost analysis utilizes several cost models including the one described in the NHTSA project above. In addition, EPA expanded the scope of the work to include an updated look (2012) at all of the mass reduction technologies and techniques so that FEV was not limited to only the ideas originally generated by Lotus which were determined in 2009. As part of this EPA Phase 2 study, FEV/EDAG analyzed the BIW ideas from Lotus's Phase 1 study through CAE modeling and FEV included the technologies for mass reduction with the information provided in the Phase 1 Lotus Engineering report for the low development scenario.

VERIFICATION OF THE LOTUS BIW DESIGN FOR NVH: Similar to Lotus Phase 1 study, the EPA Phase 2 study begins with vehicle tear down and BOM development. FEV and its subcontractors tore down a MY 2010 Toyota Venza in order to create a BOM as well as understand the production methods for each component. Approximately 140 coupons from the BIW were analyzed in order to understand the full material composition of the baseline vehicle. A baseline CAE model was created based on the findings of the vehicle teardown and analysis. The model's results for static bending, static torsion, and modal frequency simulations (NVH) were obtained and compared to actual results from a Toyota Venza vehicle. After confirming that the results were within acceptable limits, this model was then modified to create light-weighted vehicle models. EDAG reviewed the Lotus Phase 1 low development BIW ideas and found redesign was needed to achieve the full set of acceptable NVH characteristics. EDAG utilized a commercially available computerized optimization tool called HEEDS MDO to build the optimization model. The model consisted of 484 design variables, 7 load cases (2 NVH + 5 crash), and 1 cost evaluation. The outcome of EDAG's lightweight design optimization included the optimized vehicle assembly and incorporated the following while maintaining the original BIW design: optimized gauge and material grades for body structure parts, laser welded assembly at shock towers, rocker, roof rail, and rear structure subassemblies, aluminum material for front bumper, hood, and tailgate parts, TRBs on B-pillar, A-pillar, roof rail, and seat cross member parts, design change on front rail side members. EDAG achieved 13% mass reduction in the BIW including closure. If aluminum doors were included then an additional decrease of 28kg could be achieved for a total of 18% mass reduction from the body structure. All other systems within the vehicle were examined for mass reduction, including the powertrain (engine, transmission, fuel tank, exhaust, etc.). FEV and Munro incorporated the Lotus Phase 1 low development concepts into their own idea matrix. Each component and sub-system chosen for mass reduction was scaled to the dimensions of the baseline vehicle, trying to maximize the amount of mass reduction with cost effective technologies and techniques that are considered feasible and manufacturable in high volumes in MY2017. FEV included a full discussion of the chosen mass reduction options for each component and subsystem.

UPDATE RESEARCH ON MASS REDUCTION TECHNOLOGIES: FEV and Munro created a BOM based on the teardown analysis. Mass reduction technology review was conducted at the system and sub-system level. The staff at FEV and Munro consists of experts from the automotive industry and discussion also included outside venders of mass reduction technologies. Forty of the 150 Lotus Phase 1 concepts were included in the final mass reduction technology selection. SAFETY FEASIBILITY: Safety performance of the baseline and light-weighted designs (Lotus Phase 1 low development and the final EPA Phase 2 design) were evaluated by EDAG through their constructed detailed CAD/CAE vehicle models. Five federal safety crash tests were performed, including FMVSS flat frontal crash, side impact, rear impact and roof crush (using IIHS resistance requirements) as well as Euro NCAP/IIHS offset frontal crash. Criteria including the crash pulse, intrusion and visual crash information were evaluated to compare the results of the light weighted models to the results of the baseline model (which had been compared qualitatively to the available actual NHTSA crash results of the Venza). Potential compliance with safety and performance of the light weighted CAE model in FMVSS and NCAP tests was inferred using quantitative measurements of vehicle delta velocity and intrusion. The light weighted vehicle achieved equivalent safety performance in all tests to the baseline model with no damage to the fuel tank. In addition, CAE was used to evaluate the BIW vibration modes in torsion, lateral bending, rear end match boxing, and rear end vertical bending, and also to evaluate the BIW stiffness in bending and torsion.

COST ANALYSIS: The development of a bill of materials (BOM), on systems and sub-systems by FEV and Munro, was the basis for the cost analysis. This methodology is consistent with the peer reviewed approach described earlier in this chapter. The cost for the mass reduced technologies were developed by determining the difference in cost for those new components compared to the old, and under the assumption of production scales of 200,000 units (appropriate for the Venza global production). FEV and Munro developed several thousand cost spreadsheets as the basis for the cost analyses for the mass reduction technologies and the BIW and closures. Costs include manufacturing (material, labor, burden) and markup (end item scrap, Sales, General and Administrative (SG&A), Profit, Engineering, Development and Testing (ED&T) and Research and Development (R&D)). A separate tooling cost analysis was also performed and at 18% mass reduction calculated a $0.05/kg for tooling. The cost analysis of the BIW and closures were done by EDAG and were based on a Technical Cost Modeling (TCM) approach developed by the Massachusetts Institute of Technology (MIT) Materials Systems Laboratory's research[110].

RESULTS: The light-weighting effort achieved an 18% mass reduction (with downsized powertrain[nnn]) on the base 1710 kg Toyota Venza at a cost of $-0.43/kg (a cost savings) which includes tooling (cost increase of $0.04/kg). A cost curve was developed to show the estimated $/kg over a variety of mass reduction levels utilizing the subset of technologies and techniques developed throughout the study (see Figure 3-36). The two curves represent non-compounded mass reduction technologies ("primary") and compounded mass reduction scenario (a total of "primary" and "secondary"). These curves were determined by reviewing the BOM part by part and identifying the parts within systems that would benefit from mass reduction and be able to utilize mass compounding. It is important to note that the potential for secondary mass reduction was evaluated at many points along the whole cost curve. The cost curve was used to determine a value for the average cost per kilogram of cumulative mass reduction (in terms of $/kg for mass reduction at a specific mass reduction level).

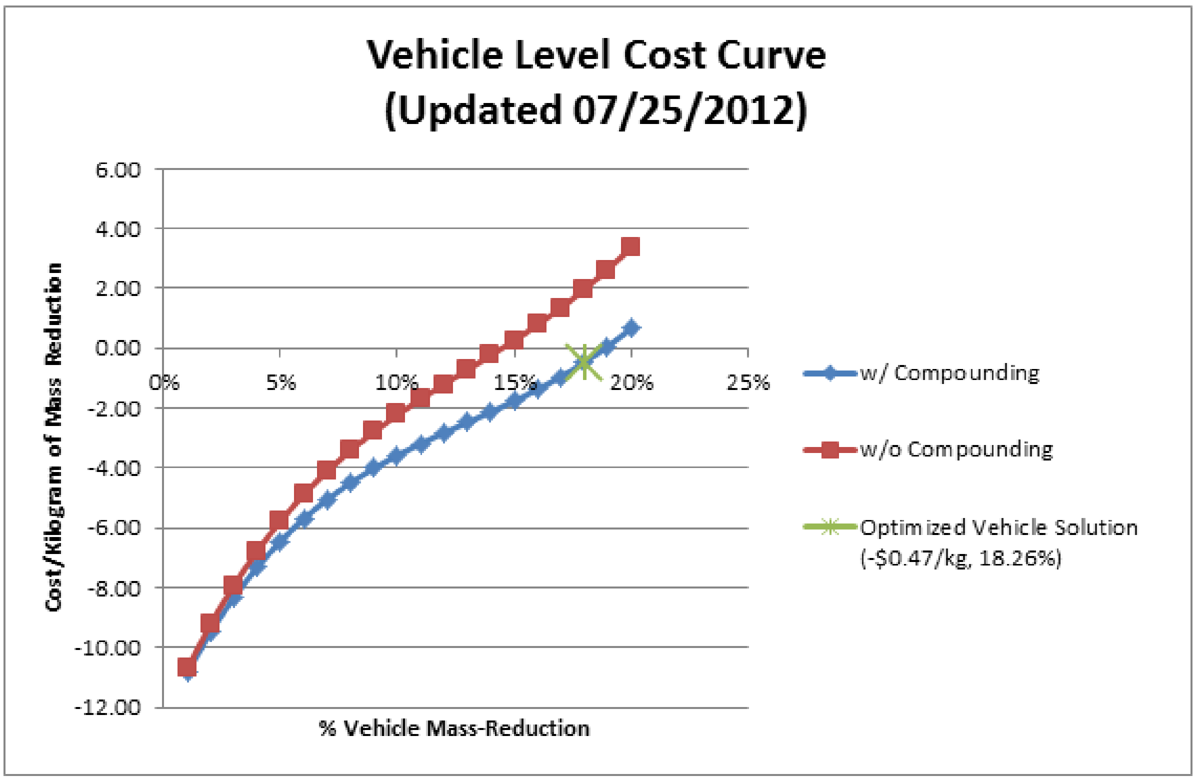


Figure 3-36 Cost Curve for the 2010 Toyota Venza – EPA Study (FEV/EDAG/Munro)

PEER REVIEW: The peer review comments for this study were generally positive and concurred with the ideas and methodology of the EPA study. The documents for the peer review can be found in EPA docket EPA-HQ-OAR-2010-0799. After accounting for peer

[nnn] The engine was downsized and downweighted, however the number of cylinders remained the same and it remained naturally aspirated.

review comments to the draft report, mass reduction decreased by 0.5% and though some of the adjustments resulted in a cost savings, the overall cost increased slightly. Changes to the BIW CAE models resulted in minimal differences.

There were many positive comments about the report. While the report included mass reduction and cost analyses for several hundred items, there were some concerns identified in the peer review comments that influenced the overall amount of mass reduction and the cost. These included 1) engine magnesium block cost, 2) the (brake) rotor design, 3) aluminum hollow suspension stabilizer bar, and 4) the closure aluminum material cost.

There were several areas where peer reviewers suggested changes that did not impact percent mass reduction or cost. First, more information was included to better describe the wheel mass technology. Second the BIW models were updated to eliminate the inconsistencies in material assignments - revising the number of through thickness integration points for the shell elements and correcting the asymmetrical thickness assignments. Finally, the baseline and optimized BIW models were further refined to include definitions of welding properties, transverse shear scale factor, element type, element formulation and material failure criteria. Based on these updates the crash models were rerun (resulting in statistically insignificant change and the results included in the final report.

California Air Resources Board Sponsored Mass Reduction Study: The California Air Resources Board (CARB) funded a study with Lotus Engineering to further develop the high development design from Lotus' 2010 Toyota Venza work ("Phase 1"). The CARB-sponsored Lotus "Phase 2" study provides the updated design, crash simulation results, detailed costing, and analysis of the manufacturing feasibility of the BIW and closures. Based on the findings of the safety validation work, Lotus made revisions to strengthen the vehicle structure through the use of a more aluminum-intensive BIW (and with less magnesium). In addition to the increased use of advanced materials, the new design by Lotus included a number of instances in which multiple parts were integrated, resulting in a reduction in the number of manufactured parts in the lightweight BIW. The Phase 2 study reports that the number of parts in the BIW was reduced from greater than 250 to less than 170. The BIW was analyzed for torsional stiffness and crash test safety with Computer-Aided Engineering (CAE). The new design's torsional stiffness was 32.9 kNm/deg, which is higher than the baseline vehicle and comparable to more performance-oriented models. The analysis included validation of the lightweight vehicle design for standard FMVSS/IIHS front, side, rear, offset, roof, intrusion, and seatbelt safety tests. Crash tests simulated in CAE showed results that were acceptable for all crash tests analyzed. No comparisons or conclusions were made if the vehicle performed better or worse than the baseline Venza. For FMVSS 208 frontal impact, Lotus based its CAE crash test analyses on vehicle crash acceleration data rather than occupant injury as is done in the actual vehicle crash. The report from the study stated that accelerations were within acceptable levels compared to current production vehicle acceleration results and it should be possible to tune the occupant restraint system to handle the specific acceleration pulses of the Phase 2 high development vehicle. FMVSS 210 seatbelt anchorages is concerned with seatbelt retention and certain dimensional constraints for the relationship between the seatbelts and the seats. Overall both the front and rear seatbelt anchorages met the requirements specified in the standard. FMVSS 214 side impact show the energy is effectively managed. Since dummy injury criteria was not used in the CAE modeling, a maximum intrusion tolerance level of 300mm was instituted which is the typical distance between the door panel and most outboard seating positions. For example, the Phase 2 design was measured at 115mm for the crabbed barrier test. The side pole test resulted in 120mm intrusion for the 5th percentile female and intrusion was measured at 190mm for the 50th percentile male. The report stated FMVSS 216 roof crush simulation shows the Phase 2 high development vehicle will meet roof crush performance requirements under the specified load case of 3 times the vehicle weight. For the FMVSS rear impact, results show plastic strain in the fuel tank/system components to be less than 3.5%, which is less than the 10% strain allowed in the test. The pressure change in the fuel tank is less than 2% so risk of tank splitting is minimal. The IIHS low speed front and rear show no body structural issues, however styling adjustments should be made to improve the rear bumper low speed performance.

The cost analysis for the Phase 2 lightweight design involved new piece, tooling, and assembly work on the BIW and closures, and the technologies and costs for the non-BIW components were carried over from the Phase 1 work. The Lotus design achieved a 37% (141 kg) mass reduction in the body structure, a 38% (484kg) mass reduction in the vehicle excluding the powertrain, and a 32% (537 kg) mass reduction in the entire vehicle including the powertrain. The Phase 2 report included an investigation into the manufacturing and assembly processes to assess whether the low mass aluminum BIW design can feasibly and cost-effectively be constructed for 60,000 units. Lotus found that the assembly and tooling cost savings, due to the lower number of BIW parts, relative to the base Venza partially offset the 60% increase in piece costs for the BIW for a resulting BIW cost increase of $239. Accounting for all of the other systems (excluding the powertrain) using the results from Phase I study, the impact is a cost savings of $476 for 484 kg reduced, or -$0.98/kg. For the complete vehicle with powertrain (hybrid powertrain), the overall cost savings for the whole vehicle including powertrain is $318 for 537 kg reduced, or -$0.59/kg. The hybrid engine was downsized from 120hp to 100hp and the corresponding hybrid system related components were removed or exchanged for a minimal change in overall mass. The report was peer reviewed by a cross section of experts, from academia, a DOE lab, DOE and an aluminum industry representative. The peer review comments were addressed in the peer review document and were incorporated in the final Phase 2 report. The documents will be found on EPA's website http://www.epa.gov/otaq/climate/publications.htm#vehicletechnologies.

NHTSA Fleet Simulation Study

NHTSA has contracted with GWU to build a fleet simulation model to study the impact and relationship of light-weighted vehicle design with injuries and fatalities. This study will also include an evaluation of potential countermeasures to reduce any safety concerns associated with lightweight vehicles in the second phase. NHTSA has included three light-weighted vehicle designs in this study: the one from Electricore/EDAG/GWU mentioned above, one from Lotus Engineering funded by California Air Resource Board for the second phase of the study, evaluating mass reduction levels around 35 percent of total vehicle mass, and one funded by EPA and the International Council on Clean Transportation (ICCT). In addition to the lightweight vehicle models, these projects also created CAE models of the baseline vehicles. To estimate the fleet safety implications of light-weighting, CAE crash simulation modeling was conducted to generate crash pulse and intrusion data for the baseline and three light-weighted vehicles when they crash with objects (barriers and poles) and with four other vehicle models (Chevy Silverado, Ford Taurus, Toyota Yaris and Ford Explorer) that represent a range of current vehicles. The simulated acceleration and intrusion data were used as inputs to MADYMO occupant models to estimate driver injury. The crashes were conducted at a range of speeds and the occupant injury risks were combined based on the frequency of the crash occurring in real world data. The change in driver injury risk between the baseline and light-weighed vehicles will provide insight into the safety performance these light-weighting design concepts. This is a large and ambitious project involves several stages over several years. NHTSA and GWU have completed the first stage of this study. The frontal crash simulation part of the study is being finished and will be peer reviewed. The report for this study will be available in NHTSA-2010-0131. Information for this study can also be found at NHTSA's website[ooo].

The countermeasures section of the study is expected to be finished in early 2013. This phase of the study is expected to provide information about the relationship of light-weighted vehicle design with injuries and fatalities and to provide the capability to evaluate the potential countermeasures to safety concerns associated with light-weighted vehicles. NHTSA plans to include the following items in future phases of the study to help better understanding the impact of mass reduction on safety.

- Simulation of crashes between two light-weighted concept vehicles;
- Additional crash configurations, such as side impact, oblique and rear impact tests;
- Risk analysis for elderly and vulnerable occupants;
- Safety of light-weighted concept vehicles for different size occupants.
- Partner vehicle protection in crashes with other light-weighted concept vehicles;

While this study is expected to provide information about the relationship of light-weighted vehicle design with injuries and fatalities and to provide meaningful information to NHTSA on potential countermeasures to reduce any safety concerns associated with lightweight vehicles, because this study cannot incorporate all of the variations in vehicle crashes that occur in the real world, it is expected to provide trend information on the effect of potential future designs on highway safety, but is not expected to provide information that can be used to modify the coefficients derived by Kahane that relate mass reduction to highway crash fatalities. Because the coefficients from the Kahane study are used in the agencies' assessment of the amount of mass reduction that may be implemented with a neutral effect on highway safety, the fact that the fleet simulation modeling study is not complete does not affect the agencies' assessment of the amount of mass reduction that may be implemented with a neutral effect on safety.

[ooo] Website for fleet study can be found at http://www.nhtsa.gov/fuel-economy.

Safety considerations in establishing CAFE/GHG standards along with discussion of NHTSA's February 25, 2011, mass-size-safety workshop at DOT headquarters, can be found in Section II.G of the preamble for this final rule. NHTSA intends to host additional workshops when the studies have reached a sufficient level of completion, to share the results with the public and continue the fruitful ongoing public dialogue on these issues.

3.5 How did the agencies consider real-world limits when defining the rate at which technologies can be deployed?

3.5.1 Refresh and redesign schedules

During MYs 2017-2025 manufacturers are expected to go through the normal automotive business cycle of redesigning and upgrading their light-duty vehicle products, and in some cases introducing entirely new vehicles not in the market today. The MY 2017-2025 standards timeframe allows manufacturers the time needed to incorporate GHG reduction and fuel-saving technologies into their normal business cycle while considering the requirements of the MY 2012-2016 standards. This is important because it has the potential to avoid the much higher costs that could occur if manufacturers need to add or change technology at times other than their scheduled vehicle redesigns. This time period also provides manufacturers the opportunity to plan for compliance using a multi-year time frame, again consistent with normal business practice. Over these 9 model years, and the 5 prior model years that make up the 2012-2016 standards, there will be an opportunity for manufacturers to evaluate, presumably, every one of their vehicle platforms and models and add technology in a cost effective way to control GHG emissions and improve fuel economy. This includes all the technologies considered here and the redesign of the air conditioner systems in ways that will further reduce GHG emissions and improve fuel economy.

Because of the complexities of the automobile manufacturing process, manufacturers are generally only able to add new technologies to vehicles on a specific schedule; just because a technology exists in the marketplace or is made available, does not mean that it can be immediately applied on all of a manufacturer's vehicles. In the automobile industry there are two terms that describe when technology changes to vehicles occur: redesign and refresh (*i.e.*, freshening). Vehicle redesign usually refers to significant changes to a vehicle's appearance, shape, dimensions, and powertrain. Redesign is traditionally associated with the introduction of "new" vehicles into the market, often characterized as the "next generation" of a vehicle, or a new platform. Across the industry, redesign of models generally takes place about every 5 years. However, while 5 years is a typical design period, there are many instances where redesign cycles can be longer or shorter. For example, it has generally been the case that pickup trucks and full size vans have longer redesign cycles (e.g., 6 to 7 years), while high-volume cars have shorter redesign cycles in order to remain competitive in the market. There are many other factors that can also affect redesign such as availability of capital and engineering resources and the extent of platform and component sharing between models, or even manufacturers.

Vehicle refresh usually refers to less extensive vehicle modifications, such as minor changes to a vehicle's appearance, a moderate upgrade to a powertrain system, or small changes to the vehicle's feature or safety equipment content. Refresh is traditionally associated with mid-cycle cosmetic changes to a vehicle, within its current generation, to make it appear "fresh." Vehicle refresh generally occurs no earlier than two years after a vehicle redesign or at least two years before a scheduled redesign. For the majority of technologies discussed today, manufacturers will only be able to apply them at a refresh or redesign, because their application would be significant enough to involve some level of engineering, testing, and calibration work.

Most vehicles would likely undergo two redesigns during the 2017-2025 period. Even with the potential of multiple refresh and redesign cycles, it is still likely that some of the more advanced and costly technologies (such as cooled boosted EGR engines, or advanced (P)HEVs) may not be able to be fully implemented within the timeframe of this rule. These limitations are captured in "phase-in caps," discussed in the next section, and "maximum technology penetration rates" within the modeling analysis.

The broad technology classes evaluated for purposes of this analysis are defined below and a brief discussion of the limiting factors considered are presented.

- Conventional Spark Ignition (SI) - This technology category includes all technologies, such as gasoline direct injection engines, cylinder deactivation, six and eight speed automatic and dual clutch transmissions, and start-stop micro-hybrid technology that are not contained in other categories. Many of these technologies were anticipated as being available in the MYs 2012-2016 time frame in the recent NHTSA and EPA final rule, and it is expected manufacturers could expand production to all models by model year 2025. Conventional SI also includes turbocharged and downsized engines and turbocharged and downsized engines that include cooled EGR with additional levels of boost and a larger degree of engine downsizing than seen in the current light-duty gasoline fleet. These latter technologies are similar to the technologies that many OEMs indicated were under development and which they anticipate will be introduced into the market in the 2017-2025 time frame.

- Hybrid – While the agencies recognize there are many types of full-hybrids either in production or under development, for the purposes of this analysis we have specifically modeled the P2 type hybrid, as explained in section 3.4.3.6.3. While the agencies expect the proliferation of these vehicles to increase in this timeframe, the maximum technology penetration rate and phase-in caps are set at less than 100% in MY 2025 due to industry-wide engineering and capacity constraints for converting the entire new vehicle fleet to strong hybrids (like P2 and others) in this time frame. As described above, these technologies (along with PHEVs and EVs) require a significant cost and complexity, and thus are not expected to be able to be fully phased into the 2017-2025 fleet like other more conventional (but advanced) engines.

- Plug-in Hybrid (PHEV) - In the agencies' analyses, this technology includes PHEVs with a range of 20, 30 and 40 miles. The maximum technology penetration rates and phase-in caps are set at less than 100% in MY 2025 due to the same general potential constraints as listed for the HEVs, but are lower for

PHEVs due to the current status of the development of these advanced vehicles and the higher cost relative to HEVs. In addition, some consumers may have limited or no access to charging infrastructure and, for those consumers, the PHEV offers little benefit over an HEV at a higher cost. Further, we project (based on what we know today) that PHEV technology is not available to some vehicle types, such as large pickups, which are expected to provide a true "work" function. While it is technically possible to electrify such vehicles, there are tradeoffs in terms of cost, electric range, and utility (e.g., loss of towing and/or payload capacity) that may limit the appeal of the vehicle to a narrower market. However, the agencies are interested in promoting innovation to overcome these potential obstacles and are thus incentivizing more HEV and PHEV pickup trucks with credit flexibilities as described in the preamble for this final rule.

- Electric Vehicle (EV) - In our analyses, this technology includes vehicles with actual on-road ranges of 75, 100, and 150 miles. The actual on-road range was calculated using a projected 30% gap between two-cycle and on-road range. These vehicles are powered solely by electricity and are not powered by any liquid fuels. The maximum technology penetration rates and phase-in caps are set at less than 100% in MY 2025 due to the same general potential constraints as discussed for PHEVs. EVs have additional constraints due to limited infrastructure and range as well. Further, as with PHEVs, we assume that EV technology is not available to some vehicle types, such as large pickups. While it is possible to electrify such vehicles, there are tradeoffs in terms of cost, range, and utility that would limit the appeal of the vehicle to a narrower market. These trade-offs are expected to reduce the market for other vehicle types as well, and for this analysis we have considered this in the development of the maximum technology penetration rates.

- Mass Reduction - This technology includes changing the design to use less material or substituting lighter materials for heavier materials. Mass reduction compounding after significant primary mass reduction is achieved can also make significant contribution to the overall vehicle mass reduction. NHTSA and EPA have conducted a thorough assessment of the levels of mass reduction that could be achieved which is both technologically feasible and which can be implemented in a safe manner for this joint federal FRM (as described earlier in this Chapter).Vehicle phase-in caps

GHG-reducing and fuel-saving technologies for vehicle applications vary widely in function, cost, effectiveness and availability. Some of these attributes, like cost and availability vary from year to year. New technologies often take several years to become available across the entire market. The agencies use phase-in caps to manage the maximum rate that the CAFE and OMEGA models can apply new technologies.

Phase-in caps are intended to function as a proxy for a number of real-world limitations in deploying new technologies in the auto industry. These limitations can include but are not limited to, engineering resources at the OEM or supplier level, restrictions on intellectual property that limit deployment, and/or limitations in material or component supply as a market for a new technology develops. Without phase-in caps, the models may apply technologies at rates that are not representative of what the industry is actually capable of producing, which would suggest that more stringent standards might be feasible than actually would be.

EPA applies the caps on an OEM vehicle platform basis for most technologies. For a given technology with a cap of x%, this means that x% of a vehicle platform can receive that technology. On a fleet average basis, since all vehicle platforms can receive x% of this technology, x% of a manufacturer's fleet can also receive that technology. EVs and PHEVs are an exception to this rule as the agencies limit the availability of these technologies to some subclasses. Unlike other technologies, in order to maintain utility, EPA only allows non-towing vehicle types to be electrified in the OMEGA model. As a result, the PHEV and EV cap was applied so that the average manufacturer could produce to the cap levels. As would be expected, manufacturers that make more non-towing vehicles can have a higher fraction of their fleet converted to EVs and PHEVs, while those that make fewer non-towing vehicles have a lower potential maximum limit on EV and PHEV production.

NHTSA applies phase-in caps in addition to refresh/redesign cycles used in the CAFE model, which constrain the rate of technology application at the vehicle level so as to ensure a period of stability following any modeled technology applications. Unlike vehicle-level cycle settings, phase-in caps, defined on a percent per year basis, constrain technology application at the OEM level. As discussed above phase-in caps are intended to reflect a manufacturer's overall resource capacity available for implementing new technologies (such as engineering and development personnel and financial resources) thereby ensuring that resource capacity is accounted for in the modeling process. At a high level, phase-in caps and refresh/redesign cycles work in conjunction with one another to avoid the CAFE modeling process out-pacing an OEM's limited pool of available resources during the rulemaking time frame, especially in years where many models may be scheduled for refresh or redesign. This helps to ensure technological feasibility and economic practicability in determining the stringency of the standards.

Phase-in caps do not necessarily define market penetration rates and they do not necessarily define the rate at which a particular technology will be applied, rather they simply present an upper limit, or ceiling at which the agencies' computer models (OMEGA and CAFE) can apply new technologies to vehicles to raise their fuel economy and reduce their CO_2 emissions. Ultimately, phase-in caps are determined by the agencies using engineering judgment. However, there are several sources of information on technology penetration that the agencies consider in assigning phase-in caps to various technologies:

- Confidential OEM submissions indicate the rate at which an individual manufacturer can deploy a particular technology. Manufacturer information is especially helpful if multiple manufacturers indicate similar technology penetration rates. The agencies consider these CBI submissions along with other sources of information.
- Historical data from EPA's annual Carbon Dioxide Emissions and Fuel Economy Trends Report[111] database are used to inform the agencies about typical historical rates of adoption of technologies. Relevant data include both

the industry-wide technology penetration data that are included in the annual Trends report, as well as individual manufacturer-specific technology penetration data that have not been published in the Trends report, but which are presented below.

- Trade press articles, company publications, press releases, and other reports often discuss new technologies, how quickly they will be deployed and manufacturing strategies that enable faster penetration rates. These articles provide a useful glimpse into how manufacturers are changing in order to become more competitive.
- The relative complexity of a technology as well as the availability from suppliers. Some technologies can be implemented rather easily—like tires. Other technologies are much more sophisticated—like hybridization.

3.5.1.1 Trends Report and Industry Data

For over 30 years, EPA's Fuel Economy Trends report has tracked the fuel economy of light duty vehicles and the technology used by automakers to improve fuel economy. A particularly interesting aspect of the Trends data is how technology is adopted by the industry and how this changes over time. Trends data shows that industry-wide, it has typically taken up to 15-20 years for a technology to penetrate the entire fleet. Some technologies such as port fuel injection and variable valve timing start slowly and then rapidly progress. Others, like torque converter lockup and front wheel drive penetrate rapidly after their first appearance on the market. Figure 3-37, below shows these trends.

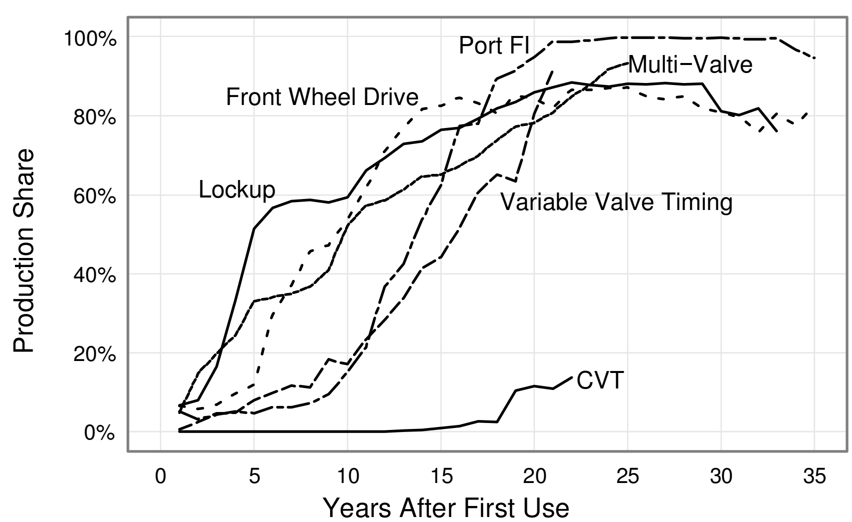


Figure 3-37 Technology Penetration After First Significant Use[112]

There are several cases where technologies have penetrated the fleet rapidly, sometimes beginning with significant market penetration, sometimes beginning with relatively small market penetration. For example, six speed automatic transmissions were in 7% of the industry-wide fleet in 2006 and by 2010, they were in 36% of the fleet, for an increase of 29% in 4 years[ppp]. Port fuel injection went from about 12% of the fleet in 1984 to 88% in 1994. Front wheel drive, a technology that requires a complete change in vehicle architecture, increased from 9% in 1979 to 60% by 1988[113].

Recent academic literature has also used deployment rate data from the EPA Fuel Economy Trends Report, Wards Factory Installed data, and other sources to report to describe historical deployment rates of a variety of technologies (DeCicco, 2010 and Zoepf, 2011). DeCicco, for example, cites conversion to fuel injection and front wheel drive in passenger cars as having seen maximum growth in adoption of 17% and 11% per year respectively.[114] Zoepf examines a broader array of automotive technologies and notes a span of maximum growth rates in passenger cars from 4% to nearly 24% per year with variance based on feature type.[115]

While these examples show that the industry is capable of adopting certain new technologies rapidly industry-wide, considering the rate of introduction of technology by individual OEMs shows that the pace of technology introduction can in some cases be even faster. Table 3-129 below shows how individual manufacturers can apply technologies rapidly to a large fraction of their fleet. Although not typical for most manufacturers and technologies, the data below shows that manufacturers have chosen to deploy some technologies very rapidly.

Table 3-129: Historical Phase-In Rates of Selected Technologies

Manufacturer	Technology	Technology Market Share Increase
General Motors	Lockup Transmission	1980-1982: 83% in 3 years
Ford	Fuel Injection	1983-1987: 91% in 5 years
Honda	Fuel Injection	1986-1990: 91% in 5 years
Chrysler	Fuel Injection	1988: 37% in 1 year
Toyota-cars only	Multi-Valve	1987-1989: 85% in 3 years
Nissan-cars only	Multi-Valve	1989-1990: 71% in 2 years
Toyota-cars only	Variable Valve Timing	2000-2003: 87% in 4 years
Ford	Multi-Valve	2004-2005: 36% in 2 years
Nissan	Continuously Variable Transmission	2007: 45% in 1 year
Volkswagen	Gasoline Direct Injection	2008: 52% in 1 year
Hyundai	Variable Valve Timing	2009: 48% in 1 year
General Motors	Variable Valve Timing	2006-2010: 75% in 5 years
General Motors	Gasoline Direct Injection	2010: 27% in 1 year

Often, a rapid application of technology is helped by having similar vehicle architecture, or by sharing major components such as engines or transmissions across multiple products. As discussed below, platform sharing combined with improvements in platform

[ppp] EPA staff calculated the penetration rate of 6-speed automatic transmissions from 2010 Trends data. Aggregated source data can be seen on page 54 of the 2010 Fuel Economy Trends Report.

and manufacturing flexibility is expected to further enable faster implementation of new technologies.

3.5.1.2 The rate of technology adoption is increasing

The agencies recognize that new technologies may not achieve rapid deployment immediately and that small-scale production is a part of the technology learning process. To this end the phase-in caps distinguish between technologies that have been successfully applied in existing vehicles and those that under development but are anticipated on production vehicles in the near future.

The rate of technology adoption appears to be increasing as manufacturers increase model turnover and decrease the numbers of unique vehicle platforms. This facilitates a steady stream of new products, increased sales and optimized vehicle redesigns allowing and fuel consumption-reducing technologies to be applied to as many vehicles as possible. In today's globally competitive market, and certainly for the U.S., market share and competitiveness is strongly influenced by a manufacturer's ability to turn over their product line-up. Merrill Lynch's Car Wars Report[116] shows that replacement rate is speeding up and showroom age is dropping as manufacturers are striving to be more competitive in the market. Increased model turn-over creates more opportunity for manufacturers to deploy new technologies faster than in the past.

Zoepf, cited above, reports that the developmental time, from first production application to maximum growth rate, has been declining exponentially as manufacturers bring innovations to market progressively faster. Ellison et al. (1995)[117] indicate that U.S. and European automakers reduced overall product development time by more than a year in the 1990s. Ellison et al. point to the increased role that suppliers have had in product development process during the same time, potentially commoditizing innovations more quickly.

Vehicle platforms are the basic underpinnings of vehicles and are often shared across several unique products. By reducing the number of platforms, and making these platforms flexible, manufacturers can better deploy resources to serve a wider market with more products. Utilizing a modern, flexible platform architecture, a manufacturer can produce a sedan, wagon, minivan, and a crossover, or SUV on a single platform and all of these products can be assembled in a single vehicle assembly plant. Basic components can be developed and purchased at high volumes, while enabling the manufacturer to exploit what would otherwise be niche markets. This commonization of platforms does have the potential to increase the mass for lighter vehicle models within the platform because the platform needs to be designed for the more severe duty cycle of the SUV and/or larger engine. Volkswagen has recently launched a new platform called MQB, which will be used world-wide by up to 60 unique models from VW, Audi, Seat, and Skoda. This structure will replace 18 "engine mounting architectures" with just two.

> *It gives us the possibility to produce models from different segments and in varying sizes using the same basic front-end architecture," …. "We can go from a typical hatchback to a saloon, cabriolet and SUV with only detailed changes to the*

size of the wheel carriers." … it will be used on every model from the new Lupo all the way through to the next-generation Sharan.[118]

One of the key enablers of this drive to reduce platforms and increase model turn-over is increased manufacturing flexibility.[119] For example, in 2004, Ford invested in flexible manufacturing technology for their Cleveland No. 1 engine plant. Although the plant was shut down for two years after this investment, Ford was able to retool and reopen the plant at a low cost to produce their new 3.5L EcoBoost turbocharged, direct injection engine as well as their 3.7L V6.[120] In their December, 2008 business plan submitted to Congress,[121] Ford further stated,

…nearly all of our U.S. assembly plants will have flexible body shops by 2012 to enable quick response to changing consumer demands and nearly half of our transmission and engine plants will be flexible, capable of manufacturing various combinations of transmission and engine families.

Like VW, Ford is also striving to reduce their platforms and complexity. In Ford's 2008 business plan submitted to Congress, they stated that in addition to divesting themselves from certain luxury brands like Jaguar, Land Rover, Volvo, and Aston Martin, they were working to consolidate their vehicle platforms from 25 in 2005 to 9 by 2012. Having more vehicles per platform frees up resources to deploy new technologies across a greater number of vehicles more quickly and increases the rate at which new technologies can be introduced. We believe GM's recent restructuring will also enable faster vehicle redesigns and more rapid penetration rates in the 2010-plus time frame compared to the 1990s and 2000s. In the past seven years, GM has eliminated five brands (Saturn, Hummer, Saab, Pontiac, and Oldsmobile), significantly reducing the number of unique products and platforms the company needed to devote engineering resources to. GM has set a goal to halve its number of vehicle platforms by 2018 and boost manufacturing efficiency by 40%.[122]

3.5.1.3 Phase-in Rates Used in the Analysis

Table 3-130 below shows phase-in rates for the technologies used in the OMEGA model. OMEGA calculations are based on five year intervals, so phase-in caps are derived for model years 2016, 2021 and 2025. Table 3-131 shows phase-in rates for the technologies used in the CAFE model. The CAFE model calculations are annual, so phase in rates are derived for every year of the program. Where possible, phase-in rates for OMEGA and CAFE were harmonized, but there are some differences mainly where technologies differ between the agencies.

Most technologies are available at a rate of either 85% or 100% beginning in 2016. Some advanced technologies expected to enter the market in the near future such as EGR Boost follow a 3% annual cap increase from 2016 to 2021, then, approximately 10% from 2021 to 2025. Diesels follow an annual 3% increase in phase-in cap through 2025. Hybrids follow a 3% annual increase from 2016 to 2012, then 5% from 2021 to 2015. PHEVs and EVs follow a 1% annual cap increase.

Lower phase-in caps for Alternate Fueled Vehicles (AFVs) reflect additional investment in infrastructure that is required to achieve high levels of conversion to a new fuel type. These limited phase-in caps also reflect as yet unknown consumer responses to HEVs, PHEVs and BEVs.

Table 3-130 Phase-In Caps used in the OMEGA model

Technology	2016	2021	2025
Low Friction Lubricants	100%	100%	100%
Engine Friction Reduction - level 1	100%	100%	100%
Early Torque Converter lockup	100%	100%	100%
Aggressive Shift Logic - Level 1	100%	100%	100%
Improved Accessories - Level 1	100%	100%	100%
Low Rolling Resistance Tires - Level 1	100%	100%	100%
Low Drag Brakes	100%	100%	100%
VVT - Intake Cam Phasing	85%	100%	100%
VVT - Coupled Cam Phasing	85%	100%	100%
VVT - Dual Cam Phasing	85%	100%	100%
Cylinder Deactivation	85%	100%	100%
Variable Valve Lift - Discrete	85%	100%	100%
Variable Valve Lift - Continuous	85%	100%	100%
Conversion to DOHC	85%	100%	100%
Stoichiometric Gasoline Direct Injection (GDI)	85%	100%	100%
Turbocharging (18 bar BMEP) and Downsizing	85%	100%	100%
Continuously Variable Transmission	85%	100%	100%
6-speed Automatic Transmission	85%	100%	100%
6-speed Dual Clutch Transmission - dry & wet clutch	85%	100%	100%
Electric & Electric/Hydraulic Power Steering	85%	100%	100%
12V Stop-Start	85%	100%	100%
Secondary Axle Disconnect	85%	100%	100%
Aero Drag Reduction - Level 1	85%	100%	100%
Aggressive Shift logic - Level 2 (Shift Optimizer)	0%	100%	100%
8-speed Automatic Transmission	30%	80%	100%
8-speed Dual Clutch Transmission - dry & wet clutch	30%	80%	100%
Improved Accessories - Level 2	30%	80%	100%
Aero Drag Reduction - Level 2	30%	80%	100%
Low Rolling Resistance Tires - Level 2	0%	75%	100%
Engine Friction Reduction - level 2 (inc. low friction lubes - level 2)	0%	60%	100%
High Effiency Gearbox	0%	60%	100%
Turbocharging (24 bar BMEP) and Downsizing	15%	30%	75%
Cooled EGR	15%	30%	75%
P2 Hybrid Electric Vehicle (HEV) and Mild Hybrid (MHEV)	15%	30%	50%
Turbocharging (27 bar BMEP) and Downsizing	0%	15%	50%

Conversion to Advanced Diesel	15%	30%	42%
Full Electric Vehicle (EV)	6%	11%	15%
Plug-in HEV	5%	10%	14%

Table 3-131 Phase-In Caps used in the CAFE Model

Technology	Abbr.	MY 2009	MY 2010	MY 2011	MY 2012	MY 2013	MY 2014	MY 2015	MY 2016	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Engine Friction Reduction - Level 1	EFR1	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	0%	0%	0%	0%	0%	0%	0%	0%	12%	24%	36%	48%	60%	72%	84%	96%	100%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Cylinder Deactivation on SOHC	DEACS	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Continuously Variable Valve Lift (CVVL)	CVVL	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Cylinder Deactivation on DOHC	DEACD	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Cylinder Deactivation on OHV	DEACO	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1_SD	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2_SD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1_SD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2_LD	0%	0%	0%	0%	0%	0%	0%	0%	3%	6%	9%	12%	15%	25%	35%	45%	50%
Advanced Diesel	ADSL_LD	0%	0%	0%	0%	3%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
6-Speed Manual/Improved Internals	6MAN	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
High Efficiency Gearbox (Manual)	HETRANSM	0%	0%	0%	0%	0%	0%	0%	0%	12%	24%	36%	48%	60%	72%	84%	96%	100%
Improved Auto. Trans. Controls/Externals	IATC	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
6-Speed Trans with Improved Internals (Auto)	NAUTO	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
6-speed DCT	DCT	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
8-Speed Trans (Auto or DCT)	8SPD	0%	0%	0%	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%
High Efficiency Gearbox (Auto or DCT)	HETRANS	0%	0%	0%	0%	0%	0%	0%	0%	12%	24%	36%	48%	60%	72%	84%	96%	100%
Shift Optimizer	SHFTOPT	0%	0%	0%	0%	0%	0%	0%	0%	20%	40%	60%	80%	100%	100%	100%	100%	100%
Electric Power Steering	EPS	5%	20%	35%	50%	65%	80%	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Improved Accessories - Level 1	IACC1	5%	20%	35%	50%	65%	80%	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Improved Accessories - Level 2	IACC2	0%	0%	0%	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%
12V Micro-Hybrid (Stop-Start)	MHEV	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Integrated Starter Generator	ISG	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	35%	40%	45%	50%
Strong Hybrid - Level 1	SHEV1	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	35%	40%	45%	50%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	35%	40%	45%	50%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	35%	40%	45%	50%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%
Plug-in Hybrid	PHEV2	0%	0%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	1%	2%	3%	4%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Mass Reduction - Level 1	MR1	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 3	MR3	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 4	MR4	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 5	MR5	0%	0%	0%	0%	0%	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Low Rolling Resistance Tires - Level 1	ROLL1	20%	35%	50%	65%	80%	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	0%	0%	0%	0%	0%	0%	0%	0%	15%	30%	45%	60%	75%	90%	100%	100%	100%
Low Drag Brakes	LDB	20%	35%	50%	65%	80%	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Secondary Axle Disconnect	SAX	15%	25%	35%	45%	55%	65%	75%	85%	95%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 1	AERO1	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%

3.6 How are the technologies applied in the agencies' respective models?

To estimate potential technology application in response to potential CAFE standards, and accompanying costs, effects, and benefits of potential CAFE standards, NHTSA uses the CAFE Compliance and Effects Modeling System, which was developed specifically for that purpose by DOT's Volpe National Transportation Systems Center (Volpe Center). To estimate potential technology application in response to potential CAFE standards, and accompanying costs, EPA uses the OMEGA model, which EPA staff developed specifically for that purpose. The models apply different but related methods to estimate and account for potential applications of technology. The models and methods are discussed in the agencies' respective RIAs and preamble sections, and in detail in documentation. The agencies have each developed modeling system inputs reflecting estimates that have been agreed to and presented above.

3.7 Maintenance and Repair Costs Associated with New Technologies

In the proposal, we requested comment on maintenance, repair, and other operating-costs and whether these might increase or decrease with the new technologies (See 76 FR 74925) We received comments on this topic from NADA. These comments stated that the agencies should include maintenance and repair costs in estimates of total cost of ownership (i.e., in our payback analyses).[qqq] NADA proffered their website (http://www.nadaguides.com/Cars/Cost-to-Own) as a place to find useful information on operating costs that might be used in our final analyses. This website tool is meant to help consumers quantify the cost of ownership of a new vehicle. The tool includes estimates for depreciation, fees, financing, insurance, fuel maintenance, opportunity costs and repairs for the first five years of ownership. The agencies acknowledge that the tool may be useful for consumers; however, there is no information provided on how these estimates were determined. Without documentation of the basis for estimates, the website information is of limited use in this rulemaking where the agencies document the source and basis for each factual assertion. Also, the costs do not extend beyond five years, which the agencies require for purposes of estimating social costs and costs of ownership throughout vehicles' useful lives. There are also evident substantive anomalies in the website information.[rrr] For these reasons, the agencies have performed an independent analysis to quantify maintenance costs.

Here we summarize what we have done for the final rule with respect to maintenance and repair costs. We distinguish maintenance from repair costs as follows: maintenance costs are those costs that are required to keep a vehicle properly maintained and, as such, are usually recommended to occur by auto makers on a regular schedule. Examples of maintenance are oil and air filter changes, tire replacements, brake pad replacement, etc. Repair costs are those costs that are unexpected and, as such, occur randomly and uniquely for every vehicle owner, if at all. Examples of repair would be parts replacement following an

[qqq] See NADA (EPA-HQ-OAR-2010-0799-9575, p.10).

[rrr] For example, comparing the 2012 Hyundai Sonata showed the same cost for fuel ($11,024) regardless of whether it is a hybrid option or not. The HEV fuel economy rating is 35/40 mpg City/Highway for the HEV and 2.4L non HEV rating is 24/35. Another example is the 2012 Ford Fusion SEL: the front wheel drive and the all-wheel drive versions have identical fuel cost despite having different fuel economies.

accident, light bulb replacement, turbocharger replacement following a mechanical failure, etc.

How each agency has folded the costs presented here into their respective final analyses is presented in each agency's respective preamble sections (section III for EPA, section IV for NHTSA) and RIAs.

The agencies have also evaluated ownership costs that include financing, sales tax, and insurance costs, and discuss those costs in TSD 4 and in each agency's respective preamble sections (section III for EPA, section IV for NHTSA) and RIAs.

3.7.1 Maintenance Costs

To estimate maintenance costs that could reasonably be attributed to these rules, the agencies have looked at vehicle models for which there exists a version with a fuel efficiency and GHG emissions improving technology and a version with the corresponding baseline technology. The difference between maintenance costs for the two models represent a cost which the agencies are attributing to this rulemaking. For example, the Ford Escape Hybrid versus the Ford Escape V6 was considered when estimating the types of maintenance cost differences that might be present for a hybrid vehicle versus a non-hybrid, and a Ford F150 with EcoBoost versus the Ford F150 5.0L was considered when estimating the types of maintenance cost differences that might be present for a turbocharged and downsized versus a naturally aspirated engine. In the case of low rolling resistance tires, we have looked at specific parts rather than specific vehicle models.

By comparing the manufacturer recommended maintenance schedule of the items being compared, we were able to estimate the differences in maintenance intervals for the two. With estimates of the costs per maintenance event, we are able to put together a picture of the maintenance cost differences associated with the "new" technology.

The technologies considered, maintenance interval comparisons, costs per maintenance event are shown in Table 3-132.

Table 3-132 Maintenance Interval and Maintenance Cost Differences for 2017-2025 Enabling Technologies (dollar values in 2010$)[a]

2017-2025 Technology	Reference Case	Control Case	Maintenance Interval Difference	Maintenance Event Cost Difference
Low Rolling Resistance Tires - Level 1	Michelin Harmony	Michelin Energy Saver A/S	Identical	+$6.44 every 40K miles
Low Rolling Resistance Tires - Level 2	Michelin Energy Saver A/S	does not exist	Identical	+$43.52 every 40K miles
Stoichiometric Gasoline Direct Injection (GDI)	2010 Hyundai Sonata 2.4L	2011 Hyundai Sonata 2.4L	Identical	+$0.00
Turbocharging (18 bar BMEP) and Downsizing	2011 F-150 5.0L	2011 F-150 EcoBoost	Identical	+$0.00

6-speed Dual Clutch Transmission - dry & wet clutch	2005 VW Jetta Auto (6-spd '09G')	2005 VW Jetta DSG (6-spd '02E'	Identical	+$0.00
Electric & Electric/Hydraulic Power Steering	2009 Ford Fusion	2010 Ford Fusion	Identical	+$0.00
12V Stop-Start	--	2013 Volvo V40	N/A	--
8-speed Automatic Transmission	2010 BMW 750i 6-spd	2010 BMW 760Li 8-spd	Identical	+$0.00
Cooled EGR	--	2013 Volvo V40	N/A	--
Conversion to Advanced Diesel	2011 VW Jetta SE 2.5L	2011 VW Jetta TDI	Identical	+$49.25 every 20K miles
Hybrid Electric Vehicle (HEV)	2012 Ford Escape V6 2012 Hyundai Sonata I4 2012 Toyota Camry V6 2012 Chevy Silverado 5.3L	2012 Ford Escape Hybrid 2012 Hyundai Sonata Hybrid 2012 Toyota Camry Hybrid 2012 Silverado 2-Mode Hybrid	Identical	+$0.00
P2 HEV	2012 Sonata V6	2013 Sonata Hybrid	N/A	--
Plug-in HEV	2012 Chevrolet Cruze	2012 Chevrolet Volt	Identical (for common service items)	+$0.00
Full Electric Vehicle (EV) – oil change	2011 Nissan Versa	2011 Nissan Leaf	No interval for EV	-$38.67 every 7.5K miles
EV – air filter change	2011 Nissan Versa	2011 Nissan Leaf	No interval for EV	-$28.60 every 30K miles
EV – spark plugs	2011 Nissan Versa	2011 Nissan Leaf	No interval for EV	-$83.00 every 105K miles
EV – brake fluid	2011 Nissan Versa	2011 Nissan Leaf	Identical	+$0.00
EV – engine coolant	2012 Ford Focus	2012 Ford Focus EV	No interval for EV	-$59.00 every 100K miles[b]
EV/PHEV[c] – battery coolant	2011 Ford Focus	2011 Ford Focus EV	No interval for Focus (gasoline)	+$117.00 every 150K miles[b]
EV – battery health check	2011 Nissan Versa	2011 Nissan Leaf	No interval for Versa	+$38.67 every 15K miles

a All maintenance interval, hours required, and part(s) cost differentials between reference and control cases were sourced from the ALLDATA subscription database (www.alldatapro.com) in January through February of 2012, unless noted otherwise in the text.

[b] These are the values the agencies used when conducting analyses. However, as newer information became available the agencies concluded these revised values (cost and interval) resided within an appropriate range given the uncertainty in how future systems will be designed. Additional information is available in bulleted text below.

[c] EPA also applied this maintenance cost adjustment to PHEVs; NHTSA did not.

Further comments and details with respect to Table 3-132:

- Low Rolling Resistance Tires – Level 1: Current Uniform Tire Quality Grading ratings (treadwear, traction, temperature) for "LRR" tires do not give a clear indication of tire life vs. conventional tires (e.g. 225/50R17 Michelin Harmony = 740 A B and Michelin Energy Saver A/S = 480 A A; whereas Goodyear Assurance Fuel Max = 580 A A and Goodyear Assurance TripleTred = 540 A A). The $6 value per maintenance event in based on the 2025MY LRRT1 incremental cost presented in Table 3-100 of this Joint TSD.

- Low Rolling Resistance Tires – Level 2: The $44 value per maintenance event in based on the 2025MY LRRT2 incremental cost presented in Table 3-100 of this Joint TSD.
- Stoichiometric GDI: 36,000 mile fuel filter interval for reference case (filter cost = $25.99), 37,500 mile interval for control case (filter cost = $34.68, or +$8.69 for every 36,000 miles). However, BMW does not require any fuel filter changes for their turbocharged GDI engines.
- Turbocharging (18 bar BMEP) and Downsizing: Oil change interval, oil type, and labor hours are identical between the reference and control cases. The reference case takes more oil - 7.7 quarts vs 6.2 quarts - but they take the exact same type of oil (5W-20 synthetic blend, Ford specification WSS-M2C9302-A). The control case uses a larger oil filter with higher filtration efficiency compared to the reference case and the cost is $13.89 vs. $9.76 or +$4.13 for the control case every 5,000 miles. However, BMW uses the exact same oil filter and oil specification in naturally aspirated and turbocharged GDI applications.
- 6 speed Dual Clutch Transmission (dry & wet): Control case requires fluid & filter change every 40,000 miles; reference case is "fill-for-life". However, the 2012 Ford Fiesta dual clutch transmission requires fluid and filter replacement at 150,000 miles; the dual clutch transmission requires 2.2 quarts of fluid and the automatic transmission requires 6.9 quarts.
- Electric & Electric/Hydraulic Power Steering: No power steering fluid changes are required in either the reference or control cases – both are "fill-for-life".
- 12 Volt Stop-Start: No information available.
- 8 speed Automatic Transmission: Replace fluid and filter at 150,000 miles for both reference and control cases.
- Cooled EGR: No information available.
- Conversion to Advanced Diesel (from gasoline): Identical oil change and air filter maintenance intervals, but different oil capacity (4.8 liters for reference case and 4.3 liters for control case), oil type (VW 502 00 for reference case and VW 507 00 for control case), and oil filter (06D115562 for reference case @ $14.00 and 071115562C for control case @ $9.00). According to VW service bulletin, "502" and "507" oil specs have converged into a single list of approved oils for the North American market, so oil change cost is assumed to be equal between gasoline and diesel engines. However, the control case requires a fuel filter change every 20,000 miles: fuel filter part number 1K0127434A @ $37.25 + 0.4 hrs labor @ $30/hr, or +$49.25 every 20,000 miles.
- Hybrid Electric Vehicle (HEV): Ford Escape in the control case has longer oil change interval (10,000 vs. 7,500 miles) compared to its reference case. However, Sonata, Camry, and Silverado reference and control cases have identical engine oil change

intervals, oil types, and labor hours, as well as identical transmission fluid change intervals and fluid types.

- P2 HEV: No information available.
- Plug-in HEV: Oil change interval, oil type, and labor hours are identical for the reference and control cases.
- Full Electric Vehicle (EV) – Oil Change: Reference case has an oil change interval every 7,500 miles: the cost is 4.4 quarts of 5W-30 @ $3.50/quart + $8.27 oil filter (part number 1520865F0C) + 0.5 hours labor @ $30/hr = -$38.67 (i.e., savings) for control case every 7,500 miles.
- Full Electric Vehicle (EV) – Air Filter Change: Reference case replacement interval is every 30,000 miles; cost is $19.60 for the part + 0.3 hours labor @ $30/hr = -$28.60 (savings) for control case every 30,000 miles.
- Full Electric Vehicle (EV) – Spark Plug Replacement: Reference case replacement interval is every 105,000 miles; cost is $32.00 for parts (4 spark plugs @ estimated $8/plug), and 1.7 hours labor @ $30/hr = -$83.00 (savings) in control case every 105,000 miles.
- Full Electric Vehicle (EV) – Brake Fluid Replacement: Interval and fluid specifications are identical in reference and control cases.
- Full Electric Vehicle (EV) – Engine Coolant Replacement: Reference case replacement interval is every 100,000 miles; cost is $29.00 for parts (7.25 quarts @ estimated $4/quart), and 1.0 hour labor (estimated) @ $30/hr = -$59.00 (savings) for control case every 100,000 miles. More recent information suggests a reference case replacement interval every 100,000 miles; cost is $21.20 for parts (5.3 quarts @ estimated $4/quart), and 1.0 hour labor (estimated) @ $30/hr = -$51.20 (savings) for control case every 100,000 miles.
- Full Electric Vehicle (EV) – Battery Coolant Replacement: Control case has a recommended battery coolant replacement 150,000 miles; uses same coolant as a gasoline engine but approximately three times the amount ($29.00 x 3 = $87.00); assume labor is the same as the gasoline engine coolant changes ($30.00) for a total cost of +$117.00 for control case every 150,000 miles. More recent information suggests that perhaps the control case should have used a recommended battery coolant replacement at 150,000 miles; uses same coolant as a gasoline engine but approximately three times the amount for a parts cost of $63.20 (15.8 quarts @ est. $4/quart); assume labor is the same as the gasoline engine coolant changes ($30.00) for a total cost of +$93.20 for control case every 150,000 miles. Also, EPA applied this cost to PHEVs as well, whereas NHTSA did not.
- Full Electric Vehicle (EV) – Battery Health Check: Two auto makers recommend periodic battery/electrical checks to run in-depth diagnostics and visual inspection; no information available on costs or interval; assume cost = cost of oil change and interval is double that for oil change; +$38.67 every 15,000 miles in control case.

There is evidence supporting that brake maintenance costs are lower in hybrid electric vehicles that are equipped with regenerative braking. The electric regeneration reduces the amount of energy that the brake system dissipates which causes less wear on the brake pads and rotors. However, the maintenance schedules do not reflect a lower frequency of maintenance; therefore, the agencies have attempted to remain consistent with the current methodology and have assumed no difference in cost (i.e., no savings).

For the first time in CAFE and GHG rulemaking, both agencies now include maintenance costs in their benefit-cost analyses and in their respective payback analyses. As noted above, please refer to each agency's preamble sections and final RIAs (Chapter 5 of EPA's RIA, Chapter VIII of NHTSA's RIA) for details of how the maintenance costs presented above are accounted for in each agency's respective analysis.

3.7.2 Repair Costs

Although NADA is correct that the agencies' NPRM analyses did not account for repair costs to equipment added as a result of these rules and incurred throughout a vehicle's useful life, the agencies' NPRM analysis did account for the costs of repairs covered by manufacturers' warranties. (See 76 FR 74925 and 74927) The indirect cost multipliers (ICMs) applied in the agencies' analyses include a component representing manufacturers' warranty costs. For the cost of repairs not covered by OEMs' warranties, the agencies evaluated the potential to apply an approach similar to that described above for maintenance costs. As for specific scheduled maintenance items, the AllData subscription database applied above provides estimates of labor and part costs for specific repairs to specific vehicle models. However, although AllData also provides service intervals for scheduled maintenance items, it does not provide estimates of the frequency at which specific failures may be expected to occur over a vehicle's useful life. The agencies have not yet been able to develop an alternative method to estimate the frequencies of different types of repairs, and are therefore unable to apply these AllData estimates in order to quantify the cost of repairs throughout vehicles' useful lives. Moreover, the frequency of repair of technologies that do not yet exist in the fleet, or are only emerging today provides insufficient representation of what they will be in the future with wider penetration of those technologies. Therefore, the agencies' central analyses supporting the final rule does not include these potential costs. However, as at proposal, our analyses do include estimated warranty costs and, therefore, the costs of repairs covered by OEMs' warranties. Repair costs are discussed further in each agency's Regulatory Impact Analysis and preamble sections.

References:

[1] U.S. EPA, "Project Report: Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe", Contract No. EP-C-11-007, Work Assignment 0-12,

[2] U.S. EPA, "Light-Duty Technology Cost Analysis Pilot Study," Contract No. EP-C-07-069, Work Assignment 1-3, December 2009, EPA-420-R-09-020, Docket EPA-HQ-OAR-2009-0472- 11282

[3] U.S. EPA, "Light-Duty Technology Cost Analysis Pilot Study Peer Review Report — Response to Comments Document", December 21, 2009, EPA-HQ-OAR-2009-0472-11285

[4] U.S. EPA, "Light-duty Technology Cost Analysis – Report on Additional Case Studies," EPA-HQ-OAR-2009-0472-11604

[5] FEV, Inc., "Light-Duty Technology Cost Analysis, Report on Additional Transmission, Mild Hybrid, and Valvetrain Technology Case Studies", Contract No. EP-C-07-069, Work Assignment 3-3. November 2011.

[6] FEV, Inc., "Light-Duty Technology Cost Analysis, Power-Split and P2 HEV Case Studies", Contract No. EP-C-07-069, Work Assignment 3-3, EPA-420-R-11-015, November 2011. Docket ID: EPA-HQ-OAR-2010-0799; Document ID: EPA-HQ-OAR-2010-0799-1101.

[7] ANL BatPaC model can be found in Docket ID EPA-HQ-OAR-2010-0799.

[8] ANL BatPaC model peer review report can be found in Docket ID EPA-HQ-OAR-2010-0799

[9] ANL BatPaC model can be found in Docket ID EPA-HQ-OAR-2010-0799.

[10] EPA-420-R-10-901, April 2010.

[11] "Interim Joint Technical Assessment Report: Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025," September 2010.

[12] 75 FR 76337.

[13] RTI International. Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. February 2009. http://www.epa.gov/otaq/ld-hwy/420r09003.pdf ; Rogozhin, A.,et al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009), doi:10.1016/j.ijpe.2009.11.031. The peer review for the RTI report is at http://www.epa.gov/otaq/ld-hwy/420r09004.pdf .

[14] Rogozhin, A.,et al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009), doi:10.1016/j.ijpe.2009.11.031.

[15] Helfand, Gloria, and Todd Sherwood, "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," August 2009.

[16] Rogozhin, A.,et al., "Using indirect cost multipliers to estimate the total cost of adding new technology in the automobile industry," International Journal of Production Economics (2009), doi:10.1016/j.ijpe.2009.11.031.

[17] Rogozhin, A., Gallaher, M., McManus, W., February 2009. Automobile industry retail price equivalent and indirect cost multipliers. EPA-420-R-09-003. Available at: /http://www.epa.gov/otaq/ld-hwy/420r09003.pdf.

[18] Rogozhin, A., Gallaher, M., McManus, W., February 2009. Automobile industry retail price equivalent and indirect cost multipliers. EPA-420-R-09-003, Table 4-3.

[19] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration (November 2011). *Draft Joint Technical Support Document: Proposed Rulemaking for 2017-2025 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards.*" EPA-420-D-11_901, available at http://www.epa.gov/otaq/climate/documents/420d11901.pdf, p. 3-12.

[20] National Research Council. Assessment of Fuel Economy Technologies for Light-Duty Vehicles. Washington, D.C.: National Academies Press, 2010.

[21] NRC, ibid, pp. 3-22, 6-16.

[22] FEV, Inc., "Potential Stranded Capital Analysis on EPA Light-Duty Technology Cost Analysis", Contract No. EP-C-07-069 Work Assignment 3-3, November 2011.

[23] 76 FR 57106 (September 15, 2011).

[24] U.S. EPA, "A Study of Potential Effectiveness of Carbon Dioxide Reducing Vehicle Technologies", Contract No. EP-C-06-003, Work Assignment 1-14, , June 2008, Report# EPA420-R-08-004, available in the EPA docket EPA-HQ-OAR-2009-0472 and on the internet at http://www.epa.gov/otaq/technology/420r08004a.pdf

[25] 76 FR 57106 (September 15, 2011)

[26] Woldring, D., Landenfeld, T., Christie, M.J., 2007, "DI Boost: Application of a High Performance Gasoline Direct Injection Concept." SAE Technical Paper Series No. 2007-01-1410.

[27] Kapus, P.E., Fraidl, G.K., Prevedel, K., Fuerhapter, A., 2007, "GDI Turbo – The Next Steps." JSAE Technical Paper No. 20075355.

[28] Hancock, D., Fraser, N., Jeremy, M., Sykes, R., Blaxill, H., 2008, "A New 3 Cylinder 1.2l Advanced Downsizing Technology Demonstrator Engine." SAE Technical Paper Series No. 2008-01-0611.

[29] Lumsden, G., OudeNijeweme, D., Fraser, N. Blaxill, H., 2009, "Development of a Turbocharged Direct Injection Downsizing Demonstrator Engine." SAE Technical Paper Series No. 2009-01-1503.

[30] Cruff, L., Kaiser, M., Krause, S., Harris, R., Krueger, U., Williams, M., 2010, "EBDI® - Application of a Fully Flexible High Bmep Downsized Spark Ignited Engine." SAE Technical Paper Series No. 2010-01-0587.

[31] Turner, J.W.G., Pearson, R.J., Curtis, R., Holland, B., 2009, "Sabre: A Cost Effective Engine Technology Combination for High Efficiency, High Performance and Low CO2 Emissions." Low Carbon Vehicles 2009: IMechE Conference Proceedings.

[32] Taylor, J., Fraser, N., Wieske, P., 2010, "Water Cooled Exhaust Manifold and Full Load EGR Technology Applied to a Downsized Direct Injection Spark Ignition Engine." SAE Technical Paper Series No. 2010-01-0356.

[33] Roth, D.B., Keller, P, Becker, M., 2010, "Requirements of External EGRSystems for Dual Cam Phaser Turbo GDI Engines." SAE Technical Paper Series No. 2010-01-0588.

[34] Burress, T.A., C.L. Coomer, S.L. Campbell, L.E. Seiber, R.H. Staunton, and J.P. Cunningham, 2008, "Evaluation of the 2007 Toyota Camry Hybrid Synergy Drive System." ORNL technical report TM-2007/190.

[35] ICF International, 2011. "Peer Review of Ricardo, Inc. Draft Report, 'Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe'". Contract No. EP-C-06-094, Work Assignment 4-04, Docket EPA-HQ-OAR-2010-0799, September 30, 2011.

[36] Ricardo Inc., "Project Report Computer Simulation of Light-duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020–2025 Timeframe," 2011, Contract No. EP-C-11-007, Work Assignment 0-12, Docket EPA-HQ-OAR-2010-0799, November, 2011.

[37] Systems Research and Applications Corporation (SRA), "Peer Draft Response to Peer Review of: Ricardo, Inc. Draft Report, 'Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe'" EPA Contract No. EP-C-11-007, Work Assignment 0-12, Docket ID EPA-HQ-OAR-2010-0799, November, 2011.

[38] Moawad, A. and Rousseau, A., "Impact of Electric Drive Vehicle Technologies on Fuel Efficiency," Energy Systems Division, Argonne National Laboratory, ANL/ESD/12-7, August 2012.

[39] "Impact of Friction Reduction Technologies on Fuel Economy," Fenske, G. Presented at the March 2009 Chicago Chapter Meeting of the 'Society of Tribologists and Lubricated Engineers' Meeting, March 18th, 2009. Available at: http://www.chicagostle.org/program/2008-2009/Impact%20of%20Friction%20Reduction%20Technologies%20on%20Fuel%20Economy%20-%20with%20VGs%20removed.pdf (last accessed July 9, 2009).

[40] "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2011", EPA-420-R-12-001a, March 2012,. Available at http://www.epa.gov/otaq/cert/mpg/fetrends/2012/420r12001a.pdf (last accessed August 7, 2012).

[41] Paul Whitaker, Ricardo, Inc., "Gasoline Engine Performance And Emissions – Future Technologies and Optimization," ERC Symposium, Low Emission Combustion Technologies for Future IC Engines, Madison, WI, June 8-9, 2005, Docket EPA-HQ-OAR-2009-0472-0155. Available at http://www.erc.wisc.edu/symposiums/2005_Symposium/June%208%20PM/Whitaker_Ricardo.pdf (last accessed Nov. 9, 2008).

[42] "Development and Optimization of the Ford 3.5L V6 EcoBoost Combustion System," Yi,J., Wooldridge, S., Coulson, G., Hilditch, J. Iyer, C.O., Moilanen, P., Papaioannou, G., Reiche, D. Shelby, M., VanDerWege, B., Weaver, C. Xu, Z., Davis, G., Hinds, B. Schamel, A. SAE Technical Paper No. 2009-01-1494, 2009, Docket EPA-HQ-OAR-2009-0472-2860.

[43] David Woldring and Tilo Landenfeld of Bosch, and Mark J. Christie of Ricardo, "DI Boost: Application of a High Performance Gasoline Direct Injection Concept," SAE 2007-01-1410. Available at http://www.sae.org/technical/papers/2007-01-1410 (last accessed Nov. 9, 2008)

[44] Yves Boccadoro, Loïc Kermanac'h, Laurent Siauve, and Jean-Michel Vincent, Renault Powertrain Division, "The New Renault TCE 1.2L Turbocharged Gasoline Engine," 28th Vienna Motor Symposium, April 2007.

[45] Tobias Heiter, Matthias Philipp, Robert Bosch, "Gasoline Direct Injection: Is There a Simplified, Cost-Optimal System Approach for an Attractive Future of Gasoline Engines?" AVL Engine & Environment Conference, September 2005.

[46] U.S. Environmental Protection Agency, "Draft Report – Light-Duty Technology Cost Analysis Pilot Study," Contract No. EP-C-07-069, Work Assignment 1-3, September 3, 2009, Docket EPA-HQ-OAR-2009-0472-0149.

[47] Kaiser, M., Krueger, U., Harris, R., Cruff, L. "Doing More with Less - The Fuel Economy Benefits of Cooled EGR on a Direct Injected Spark Ignited Boosted Engine," SAE Technical Paper Series, No. 2010-01-0589.

[48] Kapus, P.E., Fraidl, G.K., Prevedel, K., Fuerhapter, A. "GDI Turbo – The Next Steps," JSAE Technical Paper No. 20075355, 2007.

[49] "EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions," EPA420-R-08-008, March 2008, Docket EPA-HQ-OAR-2009-0472-0132.

[50] Tim Lake, John Stokes, Richard Murphy, and Richard Osborne of Ricardo and Andreas Schamel of Ford-Werke, "Turbocharging Concepts for Downsized DI Gasoline Engines," VKA/ika Aachen Colloquium 2003. *Available at* http://cat.inist.fr/?aModele=afficheN&cpsidt=16973598 (last accessed Nov. 9, 2008).

[51]http://media.gm.com/content/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2011/Jul/0722_cruze_diesel (last accessed: October 21, 2011)

[52] http://www.mazda.com/publicity/release/2010/201010/101020a.html (last accessed: October 21, 2011)

[53] U.S. EPA, "Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe", Contract No. EP-C-11-007, Work Assignment 0-12, Docket EPA-HQ-OAR-2010-0799, November, 2011.

[54] General Motors, news release, "From Hybrids to Six-Speeds, Direct Injection And More, GM's 2008 Global Powertrain Lineup Provides More Miles with Less Fuel" (released Mar. 6, 2007). *Available at http://www.gm.com/experience/fuel_economy/news/2007/adv_engines/2008-powertrain-lineup-082707.jsp* (last accessed Sept. 18, 2008).

[55] "EPA Staff Technical Report: Cost and Effectiveness Estimates of Technologies Used to Reduce Light-duty Vehicle Carbon Dioxide Emissions" Environmental Protection Agency, EPA420-R-08-008, March 2008, at page 17, Docket EPA-HQ-OAR-2009-0472-0132.

[56] FEV, Inc., "Light-Duty Technology Cost Analysis, Report on Additional Transmission, Mild Hybrid, and Valvetrain Technology Case Studies", Contract No. EP-C-07-069, Work Assignment 3-3, Docket EPA-HQ-OAR-2010-0799, November 2011.

[57] FEV, Inc., "Light-Duty Technology Cost Analysis, Report on Additional Transmission, Mild Hybrid, and Valvetrain Technology Case Studies", Contract No. EP-C-07-069, Work Assignment 3-3, Docket EPA-HQ-OAR-2010-0799, November 2011.

[58] http://automobiles.honda.com/insight-hybrid/features.aspx?Feature=ima (last accessed on March 29, 2010; web page printout is contained in Docket EPA-HQ-OAR-2009-0472 as "Honda IMA webpage.pdf").

[59] "Latest Chevrolet Volt Battery Pack and Generator Details and Clarifications." Lyle Dennis interview of Rob Peterson (GM) regarding the all-electric drive range of the GM Volt, August 29, 2007. Accessed on the Internet on June 30, 2009 at: http://gm-volt.com/2007/08/29/latest-Chevrolet-volt-battery-pack-and-generator-details-and-clarifications/

[60] "Active Combination of Ultracapacitors and Batteries for PHEV ESS." Bohn, T. U.S. Department of Energy 2009 Vehicle Technologies Merit Review, May 20, 2009, Docket EPA-HQ-OAR-2009-0472-0163.

[61] Nelson, P.A., Santini, D.J., Barnes, J. "Factors Determining the Manufacturing Costs of Lithium-Ion Batteries for PHEVs," 24th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exposition EVS-24, Stavenger, Norway, May 13-16, 2009 (www.evs24.org).

[62] Santini, D.J., Gallagher, K.G., and Nelson, P.A. "Modeling of Manufacturing Costs of Lithium-Ion Batteries for HEVs, PHEVs, and EVs," Paper to be presented at the 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exposition, EVS-25, Shenzhen, China, November 5-9, 2010 (www.evs25.org). Advance draft provided by D.J. Santini, Argonne National Laboratory, August 24, 2010.

[63] Argonne National Laboratories, "Modeling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles", Docket ID EPA-HQ-OAR-2010-0799 or NHTSA-2010-0131-0101.

[64] Peer review of report: Argonne National Laboratories, "Modeling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles", 2011 can be found in Docket ID EPA-HQ-OAR-2010-0799 or NHTSA-2010-0131-0101.

[65] Argonne National Laboratories BatPac model can be found in Docket ID EPA-HQ-OAR-2010-0799 or NHTSA-2010-0131-0102.

[66] Nelson, P., Gallagher, K., Bloom, I. Dees, D.W. "BatPac Model Beta." Microsoft Excel™-based spreadsheet model with example generic inputs and outputs. The model is available in docket EPA-HQ-OAR-2010-0799 or NHTSA-2010-0131-0102.

[67] Anderman, M. (2010) Feedback on ARB's Zero-Emission Vehicle Staff Technical Report of 11/25/2009 including attachment A: Status of EV Technology Commercialization, Advanced Automotive Batteries, January 6, 2010

[68] Frost & Sullivan (2009b) World Hybrid Electric and Electric Vehicle Lithium-ion Battery Market, N6BF-27, Sep 2009

[69] Barnett, B. (2009) "PHEV Battery Cost Assessment" TIAX LLC presentation at U.S. DOE/EERE 2009 Vehicle Technologies Program Annual Merit Review, May 19, 2009. Accessed on the Internet on November 14, 2011 at: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2009/energy_storage/es_02_barnett.pdf

[70] Boston Consulting Group (2010) Batteries for Electric Cars – Challenges, Opportunities, and the Outlook to 2020

[71] National Research Council (2010) Transitions to Alternative Transportation Technologies--Plug-in Hybrid Electric Vehicles.

[72] K. G. Gallagher, P. A. Nelson, (2010) "An Initial BatPac Variation Study" Docket ID EPA-HQ-OAR-2010-0799

[73] "Hyundai ups tech ante with Sonata Hybrid," Automotive News, August 2, 2010.

[74] "Chevrolet Stands Behind Volt With Standard Eight-Year, 100,000-Mile Battery Warranty," GM Press release (http://media.gm.com/content/media/us/en/news/news_detail.brand_gm.html/content/Pages/news/us/en/2010/July/0714_volt_battery)

[75] "Nissan's new 2012 hybrid system aims for 1.8-L efficiency with a 3.5-L V6," SAE Automotive Engineering Online, February 15, 2010.

[76] "Lithium-ion Battery," Nissan Technological Development Activities (http://www.nissan-global.com/EN/TECHNOLOGY/INTRODUCTION/DETAILS/LI-ION-EV/), 2009.

[77] Plug-in Hybrid Electric Vehicle Charging Infrastructure Review (November 2008) INL/EXT-08-15058, U.S. Department of Energy Vehicle Technologies Program – Advanced Vehicle Testing Activity. Last accessed on the Internet on November 14, 2011 at the following URL: http://avt.inl.gov/pdf/phev/phevInfrastructureReport08.pdf

[78] May, J.W., Mattilla, M. "Plugging In: A Stakeholder Investment Guide for Public Electric-Vehicle Charging Infranstructure." Rocky Mountain Institute – Project Get Ready, July 2009. Last accessed on the Internet on November 14, 2011 at the following URL: http://projectgetready.com/docs/Plugging%20In%20-%20A%20Stakeholder%20Investment%20Guide.pdf

[79] "Electric Vehicle Charging Infrastructure Deployment Guidelines - British Columbia." Report by the Electric Transportation Engineering Corporation for Natural Resources Canada and BCHydro. Last accessed on the Internet on November 14, 2011 at the following URL: http://www.bchydro.com/etc/medialib/internet/documents/environment/EVcharging_infrastructure_guidelines09.Par.0001.File.EV%20Charging%20Infrastructure%20Guidelines-BC-Aug09.pdf

[80] "Electrification Roadmap – Revolutionizing Transportation and Achieving Energy Security." Electrification Coalition, November 2009. Accessed on the Internet on November 14, 2011 at: http://www.electrificationcoalition.org/sites/default/files/SAF_1213_EC-Roadmap_v12_Online.pdf

[81] "The Disappearing Spare Tire" Edmunds.com, May 11, 2011; EPA-HQ-OAR-2010-0799. http://www.edmunds.com/car-buying/the-disappearing-spare-tire.html (last accessed 9/6/2011)

[82] see U.S Patent 5,227,425, Rauline to Michelin, July 13, 1993

[83] "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2011", EPA420-R-12-001a, U.S. Environmental Protection Agency Office of Transportation and Air Quality, March 2012

[84] Lutsey, "Review of technical literature and trends related to automobile mass-reduction technology", UCD-ITS-RR-10-10, May 2010 . EPA-HQ-OAR-2010-0799-0722. *Available at* http://pubs.its.ucdavis.edu/publication_detail.php?id=1390 (last accessed Jun. 10, 2012).

[85] Adrian Lund, IIHS, "The Relative Safety of Large and Small Passenger Vehicles." EPA-HQ-OAR-2010-0799. *Available at* http://www.nhtsa.gov/staticfiles/rulemaking/pdf/MSS/MSSworkshop-Lund.pdf (last accessed Jun. 10, 2012).

[86] Lutsey, "Review of technical literature and trends related to automobile mass-reduction technology", UCD-ITS-RR-10-10, May 2010 . EPA-HQ-OAR-2010-2009-0722. *Available at* http://pubs.its.ucdavis.edu/publication_detail.php?id=1390 (last accessed Jun. 10, 2012).

[87] Lotus Engineering, Inc. "An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle program", March 2010.

[88] Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy; National Research Council, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles", 2011. *Available at* http://www.nap.edu/catalog.php?record_id=12924 (last accessed Jun 27, 2012).

[89] Ford Sustainability Report 2010/11, http://corporate.ford.com/microsites/sustainability-report-2010-11/issues-climate-plan-economy (last accessed Aug. 26, 2011) EPA-HQ-OAR-2010-0799.

[90] ETA, US Steel, Tata Steel, "The ACP Process™ as Applied to the Future Steel Vehicle" , Docket No. EPA-HQ-OAR-2010-0799 or NHTSA-2010-0131. *Available at* http://www.eta.com/index.php/engineering/product-design-development/the-acp-process/success-stories/181-the-acp-process-as-applied-to-the-future-steel-vehicle- (last accessed Aug. 2, 2012).

[91] SAE World Congress, "Focus B-pillar 'tailor rolled' to 8 different thicknesses," Feb. 24, 2010. EPA-HQ-OAR-2010-0799. *Available at* http://www.sae.org/mags/AEI/7695 (last accessed Jun. 10, 2012).

[92] VW comments, Docket No. EPA-HQ-OAR-2010-0799 and NHTSA-2010-0131-0247, at 18.

[93] Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy; National Research Council, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles", June 3,2011. *Available at* http://www.nap.edu/catalog.php?record_id=12924 (last accessed Jun 27, 2012).

[94] Malen, E. and K. Reddy, "Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients," Auto-Steel Partnership Report, May 2007. EPA-HQ-OAR-2010-0799-1193. Available at http://www.a-sp.org/~/media/Files/Autosteel/Research/Lightweighting/mass_compoundingpdf.ashx (last accessed Jun. 27, 2012).

[95] Bull, M., R. Chavali, A. Mascarin, "Benefit Analysis: Use of Aluminum Structures in Conjunction with Alternative Powertrain Technologies in Automobiles," Aluminum Association Research Report, May 2008. Docket No. NHTSA-2010-0131-0097. Available at http://aluminumintransportation.org/downloads/IBIS-Powertrain-Study.pdf (last accessed Aug. 17, 2011).

[96] Bjelkengren, C, "The Impact of Mass Decompounding on Assessing the Value of Vehicle Lightweighting", Docket NHTSA-2010-0131, Available at http://msl.mit.edu/theses/Bjelkengren_C-thesis.pdf (last accessed Aug 3, 2012).

[97] American Iron and Steel Institute (AISI), 2009. "New Study Finds Increased Use of Advanced High-Strength Steels Helps Decrease Overall Vehicle Weight." EPA-HQ-OAR-2010-0799-1149. Also *Available at* http://www.steel.org/en/sitecore/content/Global/Document%20Types/News/2009/Auto%20-%20New%20Study%20Finds%20Increased%20Use%20of%20Advanced%20High-Strength%20Steels.aspx (last accessed on June 11, 2012). .

[98] Ford, 2010. "The 5.0 Liter is Back: 2011 Ford Mustang GT Leads Class with 412 HP, Fuel Efficiency, Chassis Dynamics." EPA-HQ-OAR-2010-0799. *Available at* http://media.ford.com/article_display.cfm?article_id=31645 (last accessed Jun. 10, 2012).

[99] Information copied from http://www.mazda.com/csr/environment/making_car/weight_reduction.html and docketed. EPA Docket: EPA-HQ-OAR-2010-0799.

[100] The New York Times, "Automakers Resolve to Drop a Few pounds", Sept 2011. http://www.nytimes.com/2011/09/18/automobiles/autoshow/in-frankfurt-automakers-vow-to-drop-a-few-pounds.html?_r=1&smid=tw-nytimeswheels&seid=auto EPA Docket EPA-HQ-OAR-2010-0799.

[101] "Survey of vehicle mass-reduction technology trends and prospects" May 18 2010. EPA-HQ-OAR-2010-0799. Also available at http://www.arb.ca.gov/msprog/levprog/leviii/meetings/051810/lutsey_its_may18_final.pdf

[102] NAS 2010, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles". June 2010, page 7-14

[103] Frank Field, Randolph Kirchain and Richard Roth, Process cost modeling: Strategic engineering and economic evaluation of materials technologies, JOM Journal of the Minerals, Metals and Materials Society, Volume 59, Number 10, 21-32. *Available at*

http://msl.mit.edu/publications/Field_KirchainCM_StratEvalMatls.pdf (last accessed Jun. 10, 2012).

[104] Electricore/EDAG/GWU, "*Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025*", NHTSA Docket NHTSA-2010-0131.

[105] "*Peer Review for 'Mass Reduction for Light-Duty Vehicles for Model Year 2017-2025'*", NHTSA Docket NHTSA-2010-0131.

[106] FEV, **"** *Light-Duty Vehicle Mass-Reduction and Cost Analysis – Midsize Crossover Utility Vehicle "*. August 2012, EPA Docket: EPA-HQ-OAR-2010-0799.

[107] Systems Research and Application Corporation, "Peer Review of Demonstrating the Safety and Crashworthiness of a 2020 Model-Year, Mass-Reduced Crossover Vehicle (Lotus Phase 2 Report)", February 2012, EPA docket: EPA-HQ-OAR-2010-0799.

[108] RTI International, "Peer Review of Lotus Engineering Vehicle Mass Reduction Study" EPA-HQ-OAR-2010-0799-0710, November 2010.

[109] RTI International, "Peer Review of Lotus Engineering Vehicle Mass Reduction Study" EPA-HQ-OAR-2010-0799-0710, November 2010.

[110] Frank Field, Randolph Kirchain and Richard Roth, Process cost modeling: Strategic engineering and economic evaluation of materials technologies, JOM Journal of the Minerals, Metals and Materials Society, Volume 59, Number 10, 21-32. *Available at* http://msl.mit.edu/pubs/docs/Field_KirchainCM_StratEvalMatls.pdf (last accessed Aug. 22, 2011). EPA-HQ-OAR-2010-0799.

[111] U.S. EPA, Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2011, http://epa.gov/otaq/fetrends.htm

[112] EPA; Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010; Figure 28, pg 69 EPA-HQ-OAR-2010-0799-0813.

[113] EPA; Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010; Table 13, pg 50. EPA-HQ-OAR-2010-0799-0813.

[114] DeCicco, J. M. (2010). A fuel efficiency horizon for U.S. automo- biles. Technical report, University of Michigan, School of Natural Resources and Environment. Report prepared for The Energy Foundation. EPA-HQ-OAR-2010-0799-0816. Available online at http://energy.umich.edu/info/pdfs/Fuel%20Efficiency%20Horizon%20FINAL.pdf.

[115] Zoepf, Stephen. (2011) "Automotive Features: Mass Impact and Deployment Characterization" Masters thesis. Massachusetts Institute of Technology, Technology and Policy Program, Engineering Systems Division. EPA-HQ-OAR-2010-0799. Also available online: http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/Zoepf_MS_Thesis.pdf

[116] Murphy, John, Bank of America Merrill Lynch, "Car Wars 2010-2013," July 15, 2009. EPA-HQ-OAR-2010-0799-0818

[117] Ellison, D. J., Clark, K. B., Fujimoto, T., and suk Hyun, Y. (1995). Product development performance in the auto industry: 1990s update. Technical report, International Motor Vehicle Program.

[118] Autocar, "VW's New Platform for 60 Models," November 12, 2009, http://www.autocar.co.uk/News/NewsArticle.aspx?AR=244881 EPA Docket EPA-HQ-OAR-2010-070

[119] Mayne, Eric, "Aligning Capacity, Demand Poses Ultimate Brain Teaser," Wards Auto, July 29, 2008. EPA Docket EPA-HQ-OAR-2010-0799-0811

[120] Pope, Byron, "Ford's Cleveland Engine No. 1 to Build 3.7L V-6," Wards Auto, March 6, 2009. EPA Docket EPA-HQ-OAR-2010-0799-0815

[121] Ford Motor Company, Ford Motor Company Business Plan Submitted to the House Financial Services Committee, December 2, 2008. EPA Docket EPA-HQ-OAR-2010-0799-0814

[122] Rogers, Christina "GM to halve number of platforms globally," Detroit News, August 10, 2011. EPA Docket EPA-HQ-OAR-2010-0799-0817.

Chapter 4: Economic and Other Assumptions Used in the Agencies' Analysis

4.1 How the Agencies use the economic and other assumptions in their analyses

Improving new vehicles' fuel efficiency and reducing greenhouse gas (GHG) emissions provides direct benefits to their buyers and users by reducing fuel consumption and fuel costs throughout those vehicles' lifetimes, stimulating increased vehicle miles traveled (VMT) through the fuel economy rebound effect, and often increasing vehicles' driving range leading to less frequent refueling. At the same time, the reduction in fuel use that results from requiring higher fuel economy and reducing GHG emissions also produces wider benefits to the U.S. economy by lowering the cost of economic externalities that result from U.S. petroleum consumption and imports. This occurs because reducing U.S. oil consumption and imports lowers the potential costs from disruptions in the flow of oil imports, reduces the sensitivity of the U.S. economy to oil price shocks, and has the potential to reduce the global price of petroleum. Reducing fuel consumption and GHGs also lowers the economic costs of environmental externalities resulting from fuel production and use, including reducing potential future human health and economic damages from changes in the global climate caused by greenhouse gas emissions, and reducing the impacts on human health from emissions of criteria air pollutants.

These social benefits are partly offset by the increase in fuel use that results from added vehicle use due to the fuel economy rebound effect, as well as by added costs from the increased congestion, crashes, and noise caused by increased vehicle use. They would also be offset by any loss in the utility that new vehicles provide to their buyers (and subsequent owners) if manufacturers include reductions in vehicles' performance, carrying capacity, or comfort as part of their strategies to comply with higher fuel economy requirements and GHG standards. However, the agencies' analyses supporting the final standards do not anticipate any such reductions in utility as being necessary, and the analysis includes the costs to manufacturers of preserving vehicle capabilities.[a] (For example, the costs of engine downsizing include the costs of turbocharging the engine to maintain its performance). The total economic benefits from requiring higher fuel economy and reducing GHG emissions are likely to be substantial, and EPA and NHTSA have developed detailed estimates of the economic benefits from adopting the final standards.

This chapter discusses the common economic and other values used by both NHTSA and EPA in their rulemaking analyses. These inputs incorporate a range of forecast information, economic estimates, and input parameters. This chapter describes the sources that EPA and NHTSA have relied upon for this information, the rationale underlying each assumption, and the agencies' estimates of specific parameter values. These common values are then used as inputs into each agency's respective modeling and other analyses of the

[a] Two exceptions – hybrid vehicles that may have some limited towing capacity, and electric vehicles – are discussed elsewhere.

economic benefits and costs of the EPA and NHTSA programs. While the underlying input values are common to both agencies, programmatic differences, and differences in the way each agency assesses its program result in differing benefit and cost estimates. This issue is discussed further in Section I.C of the preamble to the joint rulemaking. Unless otherwise noted, a summary of the public comments received on the topics described in this chapter and the agencies responses are included in the preamble Section II.E, Section III.H, and Section IV.X.

4.2 What assumptions do the agencies use in the impact analyses?

4.2.1 The on-road fuel economy "gap"

4.2.1.1 Definition and past use by EPA and NHTSA

In aggregate, actual fuel economy levels achieved by vehicles in on-road driving fall significantly short of their levels measured in the laboratory-like test conditions and two-cycle tests used under the CAFE program to determine the fuel economy ratings for different models for purposes of compliance with the CAFE and CO_2 standards. The test procedure used to determine compliance is highly controlled, and does not reflect real-world driving in a variety of ways – real-world driving tends to be more aggressive than the Federal Test Procedure (FTP) and Highway Fuel Economy Test (HFET) test cycles used to establish compliance with the GHG and CAFE regulations. Real world driving tends to include more stops and starts and more rapid acceleration/deceleration, and may include the use of technologies like air-conditioning that reduce fuel economy but that are not exercised on these test cycles.[1] There are also a number of environmental elements that affect real-world achieved fuel economy which are not measured on the two cycle compliance test, such as wind resistance, road roughness, grade, temperature, and fuel energy content. The agencies' analyses for this final rulemaking recognize this gap between compliance results and real world performance, and account for it by adjusting the fuel economy downward from its rated value.

In December 2006, EPA adopted changes to its regulations on fuel economy labeling, which were intended to bring vehicles' label fuel economy levels seen by consumers shopping for new vehicles closer to their actual on-road fuel economy levels.[2] Comparisons of on-road and CAFE fuel economy levels developed by EPA as part of its 2006 Final Rule implementing new fuel economy labeling requirements for new vehicles indicated that actual on-road fuel economy for light-duty vehicles average about 20 percent lower than compliance fuel economy ratings.[3] While there is great heterogeneity among individual drivers, as discussed in the referenced material, the 20 percent figure appears to represent an accurate average for modeling a fleet. For example, if the overall EPA fuel economy rating of a light truck is 20 MPG, the on-road fuel economy actually achieved by a typical driver of that vehicle is expected to be 16 mpg (20*.80). In its analysis supporting the Final Rule establishing CAFE standards for MY 2011, NHTSA employed EPA's revised estimate of this on-road fuel economy gap in its analysis of the fuel savings resulting from alternative fuel efficiency standards. EPA and NHTSA likewise employed this fuel economy gap for estimating fuel savings in the MYs 2012-2016 rulemaking in the Interim Joint Technical Assessment Report (TAR) analysis for MYs 2017 and later, the proposal, and in this rulemaking establishing GHG and fuel economy standards for MY 2017 and later light duty vehicles.[b]

An analysis conducted by NHTSA confirmed that EPA's estimate of a 20 percent gap between test and on-road fuel economy for the majority of vehicles is well-founded. NHTSA used data on the number of passenger cars and light trucks of each model year that were in service (registered for use) during each calendar year from 2000 through 2006; average fuel economy for passenger cars and light trucks produced during each model year; and estimates of average miles driven per year by cars and light trucks of different ages during each calendar year over that period. These data were combined to develop estimates of the usage-weighted average fuel economy that the U.S. passenger car and light truck fleets would have achieved during each year from 2000 through 2006 under test conditions.

Table 4-1 compares NHTSA's estimates of fleet-wide average fuel economy under test conditions for 2000 through 2006 to the Federal Highway Administration's (FHWA) published estimates of on-road fuel economy achieved by passenger cars and light trucks during each of those years. As it shows, FHWA's estimates of fuel economy for passenger cars ranged from 21-23 percent lower than NHTSA's estimates of its fleet-wide average value under test conditions over this period, and FHWA's estimates of fuel economy for light trucks ranged from 16-18 percent lower than NHTSA's estimates of its fleet-wide average value under test conditions. Thus, these results appear to confirm that the 20 percent on-road fuel economy gap represents a reasonable estimate for use in evaluating the fuel savings likely to result from more stringent fuel economy and CO_2 standards in MYs 2017-2025.

Table 4-1 Estimated Fleet-Wide Fuel Economy of Passenger Cars and Light Trucks Compared to Reported Fuel Economy

YEAR	PASSENGER CARS			LIGHT-DUTY TRUCKS		
	NHTSA Estimated Test MPG	FHWA Reported MPG	Percent Difference	NHTSA Estimated Test MPG	FHWA Reported MPG	Percent Difference
2000	28.2	21.9	-22.2%	20.8	17.4	-16.3%
2001	28.2	22.1	-21.7%	20.8	17.6	-15.5%
2002	28.3	22.0	-22.3%	20.9	17.5	-16.2%
2003	28.4	22.2	-21.9%	21.0	17.2	-18.0%
2004	28.5	22.5	-21.1%	21.0	17.2	-18.3%
2005	28.6	22.1	-22.8%	21.1	17.7	-16.3%

[b] The agencies did not adopt this approach in assessing benefits of the GHG emission standards and fuel consumption standards for heavy duty vehicles (76 FR 57106 (Sept. 15, 2011)) since compliance with those rules is assessed using test procedures that necessitate different modeling assumptions.

2006	28.8	22.5	-21.8%	21.2	17.8	-16.2%
Avg., 2000-2006	28.4	22.2	-22.0%	21.0	17.5	-16.7%

We are aware of two potential issues involved in these estimates. One, the estimates of total annual car and truck VMT are developed by the states and submitted to FHWA. Each state uses its own definition of a car and a truck. For example, some states classify minivans as cars and some as trucks. Thus, there are known inconsistencies with these estimates when evaluated separately for cars and trucks. Also, total gasoline consumption can be reasonably estimated from excise tax receipts, but separate estimates for cars and trucks are not available. For this reason, NHTSA and EPA are not using distinct on-road fuel economy gaps for cars and trucks, but one common value of 20 percent for both vehicle classes for purposes of estimating the fuel savings of the standards. This figure lies between the separate estimated for cars and light trucks reported in Table 4-1.

Consistent with the MYs 2012-2016 rulemaking, the TAR, and the proposal, in this final rulemaking the agencies are assuming that the on-road fuel economy gap for liquid fuel is 20 percent. As in the TAR and proposal, the agencies assume that the overall energy shortfall for the electric drivetrain (for vehicles that have those instead of or in addition to gasoline engines) is 30 percent when driven on wall electricity. The 30 percent value was derived from the agencies' engineering judgment based on several data points. Foremost among these, during the stakeholder meetings conducted prior to the Interim Joint TAR, confidential business information (CBI) was supplied by several manufacturers which indicated that electrically powered vehicles had greater variability in their on-road energy consumption than vehicles powered by internal combustion engines. Second, data from EPA's 2006 analysis of the "five cycle" fuel economy label as part of the rulemaking discussed above potentially supported a larger on-road shortfall for vehicles with hybrid-electric drivetrains[4] And third, heavy accessory load, extreme (both high and low) temperatures, and aggressive driving have deleterious impacts of unknown magnitudes on battery performance. As a counterpoint, CBI provided by several other manufacturers suggested that the on-road/laboratory differential attributable to electric operation should approach that of liquid fuel operation in the future. Consequently, 30 percent was judged by the agencies to be a reasonable estimate for the interim Joint TAR, and was carried into the analysis supporting the final rules.

The recent 2011 Fuel Economy labeling rule similarly employs a 30% on-road shortfall for electric vehicles.[5] Under the labeling program, for gasoline vehicles, there are two methods for getting label values: full 5-cycle or derived 5-cycle. Full 5-cycle means all five cycles are tested, and bag MPG results are used in a set of formulae to determine label MPG. Derived 5-cycle involves testing on the FTP and Highway tests and adjusting those values using regression-based formulae, to get label MPG values. The derived 5-cycle adjustment results in an ever-increasing adjustment in percentage terms. However, the data on which the derived 5-cycle formulae are based ends at roughly 70 MPG, where the adjustment is about 70% or an on-road gap of 30% (assuming that the five cycle formula represents the real world). For labeling purposes, lacking any EVs or PHEVs (or any vehicles beyond 70 MPG) in the database at the time this adjustment was derived, the adjustment was set at 70% for MPG values beyond 70 MPG.

Electric vehicles are allowed and expected to use the derived 5-cycle method, which suggests that their on-road gap will be approximately 30% during the near future. Individual EVs may vary, and as additional data becomes available the agencies will consider whether the 30% average gap remains appropriate.

The U.S. Coalition for Advanced Diesel Cars suggested that the on-road gap used in the proposal was overly conservative, and that advanced technology vehicles may have on-road gaps larger than 20%. The agencies recognize this potential issue – future changes in driver behavior or vehicle technology may change the on-road gap. The Coalition states that the EPA 2012 Trends Report shows that the gap for gasoline vehicles grew from 20% in 2005 to 20.5% in 2010, and that therefore the 20% value used by the agencies is understated. We note that in recognition of the potentially greater gap for electrification technologies, the agencies are using a 30% adjustment for wall electricity; but more broadly, to the extent that the Coalition is suggesting that the agencies extrapolate the growth trend in the gap into the future, the agencies do not agree that the estimate of the future on road gap would be appropriately estimated by extrapolating the historical relationship between the test procedure and real world fuel consumption and emissions. That historical rate of change occurred as a result of the specific technological changes in vehicles over that timeframe. In the future, different technologies will be employed, that are likely to affect the gap differently. As an example, while some technologies such as electrification may increase the on-road gap, other off-cycle technologies such as tire pressure management systems, air conditioning improvements and aerodynamic improvements may decrease it. Thus, the agencies are continuing to use the same on-road gap methodology as in the proposal for this final rulemaking, but will monitor the EPA fuel economy database as these vehicles enter the fleet.

Considerations in Future Years

Looking forward to MYs 2017-2025, while the agencies do not forecast changes in most of the factors discussed above that contribute to the on-road gap in ways that would change our estimates, the agencies expect that two specific factors will change somewhat that could affect this analysis. Specifically, we anticipate changes in the energy content of fuels sold at retail as a result of the recent EPA Renewable Fuel Standard 2 (RFS2) rulemaking and E15 waiver decision,[6] as well as a change in reference air conditioning efficiency as a result of the recent MYs 2012-2016 EPA Light Duty Greenhouse Gas rulemaking.

4.2.1.2 Air Conditioning

Air conditioning is a significant contributor to the on-road efficiency gap. While the air conditioner is turned off during the FTP and HFET tests, in real world use drivers often use air conditioning in warm, humid conditions. The air conditioning compressor can also be engaged during “defrost” operation of the heating system.[7] In the MYs 2012-2016 rulemaking, the agencies estimated the average impact of an air conditioning system at approximately 14.3 grams over an SCO3 test for an average vehicle without any of the improved air conditioning technologies discussed in that rulemaking. For a 27 MPG (330 g

CO_2/mile) vehicle, this is approximately 20 percent of the total estimated on-road gap, or about 4 percent of total fuel consumption.

In the MYs 2012-2016 rule, EPA estimated that 85 percent of MY 2016 vehicles would reduce their air conditioning-related CO_2 emissions by 40 percent through the use of advanced air conditioning efficiency technologies.[8] Incorporating this change would reduce the average on-road gap by about 2 percent in the reference case.[c] However, as shown in Chapter 5 of the joint TSD air conditioning-related fuel consumption does not proportionally decrease as overall engine efficiency improves. Unlike most technologies in this rulemaking, which have a multiplicative reduction on fuel consumption and CO_2 emissions, the load due to air conditioning operation is relatively constant across engine efficiency and technology. As a consequence, as engine efficiency increases, air conditioning operation represents an increasing percentage of vehicular fuel consumption.[d] To some extent, these factors are expected to counterbalance, so the agencies therefore chose not to make an air conditioning-related adjustment to the on-road gap for this rule.

4.2.1.3 Fuel Energy Content

Differences in fuel energy content between test conditions and real-world driving is another contributor to the on-road fuel economy gap. Two-cycle testing for CAFE and CO_2 compliance is based on “certification fuel” which contains no ethanol (also known as E0). The on-road fuel economy gap is estimated with reference to the difference in fuel energy content between certification fuel and 2004 retail gallons,[e] but this rule produces a reduction in petroleum based fuel consumption only.[f] Volumes of renewable fuels are statutorily fixed by the Renewable Fuel Standard, so the entirety of the energy savings will take place as reduced oil consumption. To estimate the petroleum fuel savings, we modify the on-road gap by the average difference in energy content between CY 2004 retail fuel used in the five cycle analysis and certification fuel. This results in an approximately 1% higher fuel economy than if no additional adjustment was made for fuel energy content, and corresponds to the greater energy content of certification gasoline as compared to 2004 retail gasoline.

$$E0\ Fuel\ Economy = 2\ Cycle\ Fuel\ Economy * (1 - gap) * (E0\ BTU/Gallon)\ /(2004\ BTU/gallon))$$

Where:
Gap= 20%

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[c] A 330 gram (27 MPG) vehicle has an estimated gap of about 80 grams/mile (330/0.8). Under the EPA MY 2016 rulemaking we assume a reduction of about 5 grams/mile from indirect air conditioning improvements, This A/C improvement is about 1-2% of total fuel consumption

[d] As an example, the air conditioning load of 14.3 g/mile of CO2 is a smaller percentage (4.3%) of 330 g/mile than of 260 g/mile (5.4%).

[e] The five cycle formula analysis is based on CY 2004 data.

[f] Ethanol contains approximately 76,000 British Thermal Units (Btu) per gallon as compared to petroleum gasoline (Indolene), which contains approximately 115,000 Btu. Thus, a 10 percent ethanol (E10) blend contains approximately 3.3 percent less energy than a gallon of E0, and an E15 blend contains approximately 5.1 percent less energy than a gallon of E0.

E0 BTU/Gallon = 115,000
2004 BTU/Gallon = 113,912 (3.14% ethanol, 96.86% petroleum gasoline)

A related adjustment in fuel energy was made in order to "match" fuel savings to the fuel prices used in this analysis. As discussed below, the agencies use liquid fuel prices from the Energy Information Administration's (EIA) Annual Energy Outlook (AEO) 2012 Early Release reference case.[g] By contrast, and as shown above, the gasoline savings from this rule are calculated as gallons of certification fuel, which is more energy dense than ethanol blended market fuel. To appropriately apply the AEO prices on a dollar per btu basis, we adjust our certification fuel savings upwards by approximately 5% (the difference between the energy content of E15 retail fuel and certification) when monetizing the fuel savings. This adjustment more appropriately reflects AEO projections of motor gasoline energy prices.

4.2.2 Fuel prices and the value of saving fuel

Projected future fuel prices are a critical input into the preliminary economic analysis of alternative fuel economy and GHG standards, because they determine the value of fuel savings both to new vehicle buyers and to society. For the final rule, EPA and NHTSA relied on the most recent fuel price projections from the U.S. Energy Information Administration's (EIA) *Annual Energy Outlook* (AEO) for this analysis, the AEO 2012 Early Release Reference Case. The Reference Case forecasts inflation-adjusted (constant-dollar) retail gasoline and diesel fuel prices and represents the EIA's most up-to-date estimate of future prices for petroleum products. In the Executive Summary to AEO 2012 Early Release, the Energy Information Administration describes the reference case. They state that:

> "Projections in the Annual Energy Outlook 2012 (AEO2012) Reference case focus on the factors that shape U.S. energy markets in the long term, under the assumption that current laws and regulations remain generally unchanged throughout the projection period. The AEO2012 Reference case provides the basis for examination and discussion of energy market trends and serves as a starting point for analysis of potential changes in U.S. energy policies, rules, or regulations or potential technology breakthroughs."[h]

The Reference case projection is a business-as-usual trend estimate, given known technology and technological and demographic trends. The agency has published annual projections of energy prices and consumption levels for the U.S. economy since 1982 in its Annual Energy Outlooks. These projections have been widely relied upon by federal agencies for use in regulatory analysis and for other purposes. Since 1994, EIA's annual forecasts have been based upon the agency's National Energy Modeling System (NEMS), which includes detailed representation of supply pathways, sources of demand, and their interaction to determine prices for different forms of energy.

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[g] EIA projects that the average gallon of retail motor gasoline contains 5.040 mmbtu/barrel (Higher Heating Value), as compared to 5.253 mmbtu/barrel for pure motor gasoline, which is a difference of approximately 4.5% (AEO 2012 Early Release table 147).
[h] AEO 2012 ER overview - http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2012).pdf

Several commenters (Volkwagen, Consumer Federation of America, Environmental Defense Fund, Consumer's Union, National Resources Defense Council, Union of Concerned Scientists) noted that the EIA future fuel price projections used in the proposal were similar to current prices, "modest," or lower than expected. Other commenters noted the uncertainty projecting during this extended time period (National Automobile Dealers' Association). No commenters offered alternative sources for fuel price projection, and in this final rulemaking, the agencies continue to rely upon EIA projections of future gasoline and diesel prices.

As compared to the gasoline prices used in the proposal-, which relied on projections from AEO 2011, the AEO 2012 Early Release Reference Case fuel prices are somewhat higher. A comparison is presented below in Table 4-2.

Table 4-2 Gasoline Prices for Selected Years in AEO 2011 and 2012

(Presented in constant 2010$ and including all taxes)

	2015	2020	2030
AEO 2011	$3.17	$3.42	$3.68
AEO 2012 (ER)	$3.53	$3.76	$4.04

The retail fuel price forecasts presented in AEO 2012 Early Release span the period from 2009 through 2035. Measured in constant 2010 dollars, the AEO 2012 Early Release Reference Case projections of retail gasoline prices during calendar year 2017 is $3.63 per gallon, rising gradually to $4.09 by the year 2035 (these values include federal and state taxes). However, valuing fuel savings over the full lifetimes of passenger cars and light trucks affected by the standards for MYs 2017-25 requires fuel price forecasts that extend through approximately 2060, approximately the last year during which a significant number of MY 2025 vehicles will remain in service.[i] Due to the difficulty in accurately projecting fuel prices over this long time span, the agencies have used a simple method for extrapolation over the out years. To obtain fuel price forecasts for the years 2036 and later, the agencies assume that retail fuel prices will continue to increase after 2035 at the average annual rate (0.8%) projected for 2017-2035 in the AEO 2012 Early Release Reference Case. The years between 2008 and 2016 were not included in the extrapolation due to the high volatility in the AEO projection for those years This assumption results in a projected retail price of gasoline that reaches $4.57 in 2050.

The value of fuel savings resulting from improved fuel economy and reduced GHG emissions to buyers of light-duty vehicles is determined by the retail price of fuel, which includes federal, state, and any local taxes imposed on fuel sales. Total taxes on gasoline, including federal, state, and local levies, averaged $0.43 per gallon during 2008, while those

[i] NHTSA defines the maximum lifetime of vehicles as the highest age at which more than 2 percent of those originally produced during a model year remain in service. In the case of light trucks, for example, this age has been assumed at 37 years for this analysis, see section 4.2.3.

levied on diesel averaged $0.46. Because fuel taxes represent transfers of resources from fuel buyers to government agencies, rather than real resources that are consumed in the process of supplying or using fuel, their value must be deducted from retail fuel prices to determine the value of fuel savings resulting from more stringent fuel efficiency and GHG standards to the U.S. economy.[9] When calculating the value of fuel saved by an individual driver, however, these taxes are included as part of the value of realized fuel savings. Over the entire period spanned by the agencies' analysis, this difference causes each gallon of fuel saved to be valued by about $0.36 (in constant 2010 dollars) more from the perspective of an individual vehicle buyer than from the overall perspective of the U.S. economy.[j]

In the estimates of costs and benefits presented in the preamble and in the agencies' RIAs, the agencies have included the full fuel savings over vehicles' expected lifetimes, discounted to their present values using both 3 and 7 percent discount rates. Additional discussion of this approach can be found in preamble Sections III.H and IV.C.3.

4.2.3 Vehicle Lifetimes and Survival Rates

The agencies' analyses of fuel savings and related benefits from adopting more stringent fuel economy and GHG standards for MYs 2017-2025 passenger cars and light trucks begin by estimating the resulting changes in fuel use over the entire lifetimes of affected cars and light trucks. The change in total fuel consumption by vehicles produced during each of these model years is calculated as the difference in their total lifetime fuel use over the entire lifetimes of these vehicles as compared to a reference case.

The first step in estimating lifetime fuel consumption by vehicles produced during a model year is to calculate the number of those vehicles expected to remain in service during each future calendar year after they are produced and sold.[k] This number is calculated by multiplying the number of vehicles originally produced during a model year by the proportion expected to remain in service at the age they will have reached during each subsequent calendar year, often referred to as a "survival rate."

[j] For society, the fuel taxes represent a transfer payment. By contrast, an individual realizes savings from not paying the additional money.

[k] Vehicles are defined to be of age 1 during the calendar year corresponding to the model year in which they are produced; thus for example, model year 2000 vehicles are considered to be of age 1 during calendar year 2000, age 2 during calendar year 2001, and to reach their maximum age of 30 years during calendar year 2029. NHTSA considers the maximum lifetime of vehicles to be the age after which less than 2 percent of the vehicles originally produced during a model year remain in service. Applying these conventions to vehicle registration data indicates that passenger cars have a maximum age of 30 years, while light trucks have a maximum lifetime of 37 years. *See* Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/Pubs/809952.pdf (last accessed Sept. 9, 2011). For the Final Rule, the survivability schedules developed by Lu were updated using national vehicle registration data collected by R.L. Polk for calendar years 2006 – 2010.

The proportions of passenger cars and light trucks expected to remain in service at each age are estimated from R.L. Polk vehicle registration data for calendar years 1970-2010, and are shown in Table 4-3. [10] Note that these survival rates were calculated against the pre-MY 2011 definitions of cars and light trucks, and are not projected to change over time in the analysis. The rates are applied to vehicles based on their regulatory class (passenger car or light truck) regardless of fuel type or level of technology.

The survival and annual mileage estimates reported in this section's tables reflect the convention that vehicles are defined to be of age 1 during the calendar year that coincides with their model year. Thus for example, model year 2017 vehicles will be considered to be of age 1 during calendar year 2017. This convention is used in order to account for the fact that vehicles produced during a model year typically are first offered for sale in June through September of the preceding calendar year (for example, sales of a model year typically begin in June through September of the previous calendar year, depending on manufacturer). Thus, virtually all of the vehicles produced during a model year will be in use for some or all of the calendar year coinciding with their model year, and they are considered to be of age 1 during that year.[1]

[1] A slight increase in the fraction of new passenger cars remaining in service beyond age 10 has accounted for a small share of growth in the U.S. automobile fleet. The fraction of new automobiles remaining in service to various ages was computed from R.L. Polk vehicle registration data for 1977 through 2005 by the DOT's Center for Statistical Analysis.

Table 4-3 Survival Rates

VEHICLE AGE	ESTIMATED SURVIVAL FRACTION CARS	ESTIMATED SURVIVAL FRACTION LIGHT TRUCKS
1	1.0000	1.0000
2	0.9878	0.9776
3	0.9766	0.9630
4	0.9614	0.9428
5	0.9450	0.9311
6	0.9298	0.9152
7	0.9113	0.8933
8	0.8912	0.8700
9	0.8689	0.8411
10	0.8397	0.7963
11	0.7999	0.7423
12	0.7556	0.6916
13	0.7055	0.6410
14	0.6527	0.5833
15	0.5946	0.5350
16	0.5311	0.4861
17	0.4585	0.4422
18	0.3832	0.3976
19	0.3077	0.3520
20	0.2414	0.3092
21	0.1833	0.2666
22	0.1388	0.2278
23	0.1066	0.2019
24	0.0820	0.1750
25	0.0629	0.1584
26	0.0514	0.1452
27	0.0420	0.1390
28	0.0337	0.1250
29	0.0281	0.1112
30	0.0235	0.1028
31	0.0000	0.0933
32	0.0000	0.0835
33	0.0000	0.0731
34	0.0000	0.0619
35	0.0000	0.0502
36	0.0000	0.0384
37	0.0000	0.0273

4.2.4 VMT

The second step in estimating lifetime fuel use by the cars or light trucks produced during a future model year is to calculate the total number of miles that they will be driven during each year of their expected lifetimes. To estimate total miles driven, the number of cars and light trucks projected to remain in use during each future calendar year is multiplied by the average number of miles a surviving car or light truck is expected to be driven at the age it will have reached in that year. Estimates of average annual miles driven by cars and light trucks of various ages were developed by NHTSA from the Federal Highway Administration's 2009 National Household Travel Survey. This updates the schedules of annual miles driven that were used in the NPRM, which were based on the previous National Household Travel Survey, conducted in 2001. Additionally, the agencies have accounted for the higher usage of fleet vehicles, which include rental vehicles as well as those owned by corporations and government agencies. These represent about 20% of new vehicle sales, are not represented in the NHTS, and are driven much more intensively (on average) than household vehicles for the first several years of their lives before being absorbed into the household vehicle population.[m] The updated mileage schedules are reported in Table 4-4. These estimates represent the average number of miles driven by a surviving light duty vehicle at each age over its estimated full lifetime. To determine the number of miles a typical vehicle produced during a given model year is expected to be driven at a specific age, the average annual mileage for a vehicle of that model year and age is multiplied by the corresponding survival rate for vehicles of that age. NHTSA has documented these analyses in a memo to the docket.

[m] Using the Annual Energy Outlook 2012, early release version of the National Energy Modeling System, developed and maintained by the U.S. Energy Information Administration, the proportion of fleet vehicles and their typical usage were calculated and then averaged into the household mileage accumulation schedules developed using the 2009 NHTS.

Table 4-4 CY 2009 Mileage Schedules based on NHTS Data

VEHICLE AGE	ESTIMATED VEHICLE MILES TRAVELED CARS	ESTIMATED VEHICLE MILES TRAVELED LIGHT TRUCKS
1	14,700	15,974
2	14,252	15,404
3	14,025	14,841
4	13,593	14,435
5	13,324	14,038
6	13,064	13,650
7	12,809	12,590
8	11,378	12,192
9	11,087	11,810
10	10,806	11,443
11	10,535	11,091
12	10,273	10,755
13	10,021	10,434
14	9,779	10,129
15	9,547	9,839
16	9,324	9,564
17	9,111	9,305
18	8,908	9,061
19	8,714	8,833
20	8,530	8,620
21	8,356	8,423
22	8,192	8,241
23	8,037	8,075
24	7,892	7,923
25	7,757	7,788
26	7,632	7,668
27	7,516	7,563
28	7,410	7,473
29	7,314	7,399
30	7,227	7,341
31	7,151	7,298
32	7,083	7,270
33	7,026	7,258
34	6,979	7,246
35	6,941	7,233
36	6,912	7,221
37	6,894	7,209

Projecting Vehicle Use in Future Years

The estimates of annual miles driven by passenger cars and light trucks at each age were also adjusted to reflect projected future growth in average use for vehicles of all ages. Increases in the average number of miles cars and trucks are driven each year have been an important source of historical growth in *total* car and light truck use, and are expected to be a continued source of future growth in total light-duty vehicle travel as well. As an illustration of the importance of growth in average vehicle use, the total number of miles driven by passenger cars increased 35 percent from 1985 through 2005, equivalent to a compound annual growth rate of 1.5 percent.[11] During that same time, however, the total number of passenger cars registered in the U.S. grew by only about 0.3 percent annually.[n] Thus growth in the average number of miles automobiles are driven each year accounted for the remaining 1.2 percent (= 1.5 percent - 0.3 percent) annual growth in total automobile use.[o]

In the U.S., overall change in VMT is attributable to factors such as employment rate, vehicle ownership rates, demographic trends, the cost of driving, and other macroeconomic factors. Rather than independently developing estimates of these factors, the agencies have used the DOT Volpe Center NEMS[p] run which considers many of these factors, as a benchmark of total VMT levels in each future year. The VMT projections produced by this NEMS run are highly similar to those shown in AEO 2012 Early Release. The AEO 2012 Early Release Reference Case projection of total car and light truck use and of the number of cars and light trucks in use suggest that their average annual use will continue to increase from 2010 through 2035, although at a slower rate of increase than shown in AEO 2011.[q] In calendar year 2030, total VMT projected in AEO 2012 Early Release is 10% lower than that projected in AEO 2011.

In order to develop reasonable estimates of future growth in the average number of miles driven by cars and light trucks of all ages, the agencies calculated the average rate of growth in the mileage schedules necessary for total car and light truck travel to closely correspond to AEO 2012 Early Release Reference Case. The growth rate in average annual

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[n] A slight increase in the fraction of new passenger cars remaining in service beyond age 10 has accounted for a small share of growth in the U.S. automobile fleet. The fraction of new automobiles remaining in service to various ages was computed from R.L. Polk vehicle registration data for 1977 through 2005 by the agency's Center for Statistical Analysis.

[o] *See supra* note k below.

[p] This is the version of NEMS that is used in AEO 2012 Early Release, and modified by the Volpe center to hold new vehicle fuel economy constant after 2016. See TSD 1 for additional details. This version produces VMT estimates that are highly similar to those in the AEO 2012 Early Release

[q] The agencies note that VMT growth has slowed, and because the impact of VMT is an important element in our benefit estimates, we will continue to monitor this trend to see whether this is a reversal in trend or temporary slowdown. See the 2009 National Household Travel Survey (http://nhts.ornl.gov/2009/pub/stt.pdf) and National Transportation Statistics (http://www.bts.gov/publications/national_transportation_statistics/html/table_04_09.html)

car and light truck use produced by this calculation is approximately 0.6 percent per year.[r] When the 0.6% annual growth rate is combined with the MY 2010 base sales projection (TSD 1), as well as the VMT, and survival schedules derived for this rule (previously discussed in sections 4.2.3 and 4.2.4) the estimated total vehicle usage closely approximates that contained in AEO 2012 ER (section 4.2.4.2). In the agencies' respective modeling, a growth rate is applied to the mileage figures reported in Table 4-4 (after adjusting vehicle populations for expected vehicle survival rates) to estimate average annual mileage during each calendar year analyzed and during the expected lifetimes of model year 2017-25 cars and light trucks[s]

While EPA used this aggregate approach, accounting for all factors that influence reference case VMT in a single annual growth factor of 0.6%, NHTSA separated the changing cost of driving into a second factor, and therefore used a secular growth rate of 0.5%. We discuss the agencies' two approaches in more detail below.

In the NHTSA analysis, the elasticity of annual vehicle use with respect to fuel cost per mile was applied to the percentage change in cost-per-mile travel between each future year's vehicle and the cost per mile of a vehicle that was the same age in calendar year 2008. Thus, the NHTSA method of modeling the rebound effect captures changes both in fuel cost relative to calendar year 2008 and in the fuel consumption rates relative to that year, and inherently assumes the same response to changes in fuel price and fuel efficiency.

$$\text{Percent difference in VMT} = (\text{rebound effect} * (FCPM_{2008} - FCPM_{\text{CAFE Alternative}})/FCPM_{2008})$$

Where FCPM = fuel cost per mile

EPA developed the reference case VMT using the single growth factor discussed above; this single growth factor reflects driver responsiveness to changes in projected fuel prices and fuel efficiency, and other factors consistent with the AEO 2012 ER Reference Case. To develop EPA's policy case VMT, EPA applied the elasticity of annual vehicle use with respect to fuel cost per mile corresponding to the 10 percent fuel economy rebound effect used in this analysis (*i.e.*, an elasticity of annual vehicle use with respect to fuel cost per mile driven of -0.10; see Section 4.2.5) was applied to the percentage change in cost-per-mile travel between each future year's vehicle under a policy case and a reference case in the same year. In other words, if the per mile fuel cost of a MY 2025 vehicle under the policy case was 30% less than its counterpart under the reference case, the change in VMT would be 3%.[t]

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[r] It was not possible to estimate separate growth rates in average annual use for cars and light trucks, because of the significant reclassification of light truck models as passenger cars discussed previously.

[s] As indicated previously, a vehicle's age during any future calendar year is uniquely determined by the difference between that calendar year and the model year when it was produced.

[t] Under the equation: percent difference in VMT = (rebound effect * ($FCPM_{\text{reference case}} - FCPM_{\text{policy case}}$)/$FCPM_{\text{reference case}}$) and the rebound effect = 10%. A 30% change in fuel costs, multiplied by a 10% rebound effect would result in 3% additional driving.

Thus, in the EPA analysis, the rebound effect only captures the impact of the EPA program relative to the reference case standards. Reference case changes in the cost of fuel or fuel consumption rates are handled separately. In other words, the change in VMT relative to the reference case is proportional to

$$\text{Percent difference in VMT} = (\text{rebound effect} * (FCPM_{\text{reference case}} - FCPM_{\text{policy case}})/FCPM_{\text{reference case}})$$

Where FCPM = fuel cost per mile

As a result of the difference between the two approaches of capturing the future impact of fuel prices and fuel efficiency on VMT, the agencies also differ on how they ensured consistency with growth in total vehicle use across the entire fleet (including older vehicles already in the population that are not impacted by this rule). EPA uses the 0.6% annual estimate of secular VMT growth directly in the OMEGA model. By contrast, since the NHTSA model considers the effects of changes in fuel cost per mile since the 2009 NHTS as the reference point of the fuel economy rebound effect, in order to avoid double counting the effect of changes in fuel cost per mile, NHTSA uses a growth factor of 0.5%. NHTSA separated the growth rate because of its need for consistent results among the alternative scenarios and baselines it considered in this rulemaking. For the primary case, these approaches yield highly similar estimates of VMT schedules, and consequently of total VMT (see Table 4-5).

Thus, the agencies each made adjustments to vehicle use to account for projected changes in future fuel prices, fuel efficiency, and other factors that influence growth in average vehicle use during each future calendar year. Because the effects of fuel prices and other factors influencing growth in average vehicle use differ for each year, these adjustments result in different VMT schedules for each future model year. The net impact resulting from these adjustments is continued growth over time in the average number of miles that vehicles of each age are driven, although at slower rates than those observed from 1985 – 2005. [u]

4.2.4.1 VMT equation[v]

The following equation summarizes in mathematical form the adjustments that are made to the values of average miles driven by vehicle age derived from the 2009 NHTS to derive the estimates of average miles driven by vehicles of each model year during future

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[u] Observed aggregate VMT in recent years has actually declined (about 0.4% per year over the past decade), but it is unclear if the underlying cause is general shift in behavior or a response to a set of temporary economic conditions.

[v] While both agencies applied the VMT calculation described above in the NPRM, for the final rule, in the EPA baseline calculation, the rebound effect is in effect embedded in the growth rate. Under the regulatory alternatives, the rebound effect is based solely on the percentage increase in fuel economy over the relevant baseline model year. NHTSA continued to follow the NPRM approach because of its requirement to produce an Environmental Impact Statement for the rule, and the need for consistent results among the alternative scenarios it considers.

calendar years that are used in this analysis.

$$VMT_{calendar\ year\ x,age\ y} = \left(V_y\right) * (1 + GR)^{YS}(1 - R * (FCPM_{t,y} - FCPM_{x,y})/FCPM_{t,y}$$

Where:
V_y = Average miles driven in the base calendar year (from NHTSA analysis of 2009 NHTS data) by a vehicle of age $_y$ during the base calendar year
G1 = Growth Rate
YS = Years since the base calendar year
R= Elasticity of VMT with respect to FCPM (-0.10). Note that, for EPA, this value is zero in the reference case since EPA's G1 already incorporates impacts on VMT due to changes in FCPM.
$FCPM_{x,y}$ = Fuel cost per mile of a vehicle of age *y* in calendar year *x*
$FCPM_{t,y}$ = For NHTSA, the fuel cost per mile of a vehicle of age *y* in calendar year 2008. For EPA, this variable is identical to $FCPM_{x,y}$ in the reference case, and in the policy case this variable represents the fuel cost per mile of a reference case vehicle of age *y* in calendar year t
For NHTSA, the base calendar year is 2008, for EPA 2009.

In turn, fuel cost per mile of an age y vehicle in calendar year x is determined by the following equation, which can be extended for any number of fuels:

$$FCPM_{Calendar\ year\ x} = EC_y * EP_x + GC_y * GP_x + DC_y * DP_x$$

Where:
EC_y= Electricity consumption of age *y* vehicle (in KWh) per mile
EP_x = Electricity Price (in $ per KWh) during calendar year *x*
GC_y = Gasoline Consumption of age *y* vehicle (in gallons) per mile
GP_x = Gasoline Price (in $ per gallon) during calendar year *x*
DC_y = Diesel Consumption of age *y* vehicle (in gallons) per mile
DP_x = Diesel Price (in $ per gallon) during calendar year *x*

The NHTSA and EPA models project slightly different fuel costs per mile for vehicles affected by the proposed standards, because of the different structures of the respective agencies' programs and the different technologies projected by each agency's model to be used by vehicle manufacturers to comply with each program. Over the entire lifetimes of those vehicles, however, the agencies' estimates of the number of miles they are expected to be driven differ by about 1% for cars and less than 1% for light trucks. For comparison, Table 4-5 presents the agencies' estimates of the average number of miles driven by model year 2021 and 2025 cars and light trucks at over their estimated average lifetimes.

Table 4-5 Survival Weighted Per-Vehicle Reference VMT used in the Agencies' Analyses

	MY 2021		MY 2025	
	Cars	Light Trucks	Cars	Light Trucks
EPA	204,161	218,399	209,037	223,688
NHTSA	206,768	218,812	211,795	223,865

4.2.4.2 Comparison to other VMT Projections

As a check on their estimates of vehicle use, the agencies compared the forecasts of aggregate car and light truck VMT derived using the procedure described in preceding sections to the AEO 2012 Early Release reference case forecast of light duty VMT (see Figure 4-1). Using the MY 2010 baseline, which includes the AEO 2012 ER fleet projection, the aggregate VMT projected in this analysis is within 1% of the AEO 2012 Light Duty projections over the time period 2017-2035.[12] If AEO VMT is linearly extrapolated at the average growth rate of the period 2017-2035, the agencies' estimates remain within 2% of this projection through 2050. EPA's VMT estimates are compared to the AEO projection in the chart below, but based on the similarity of VMT schedules, is indicative of both agencies' analysis.[w]

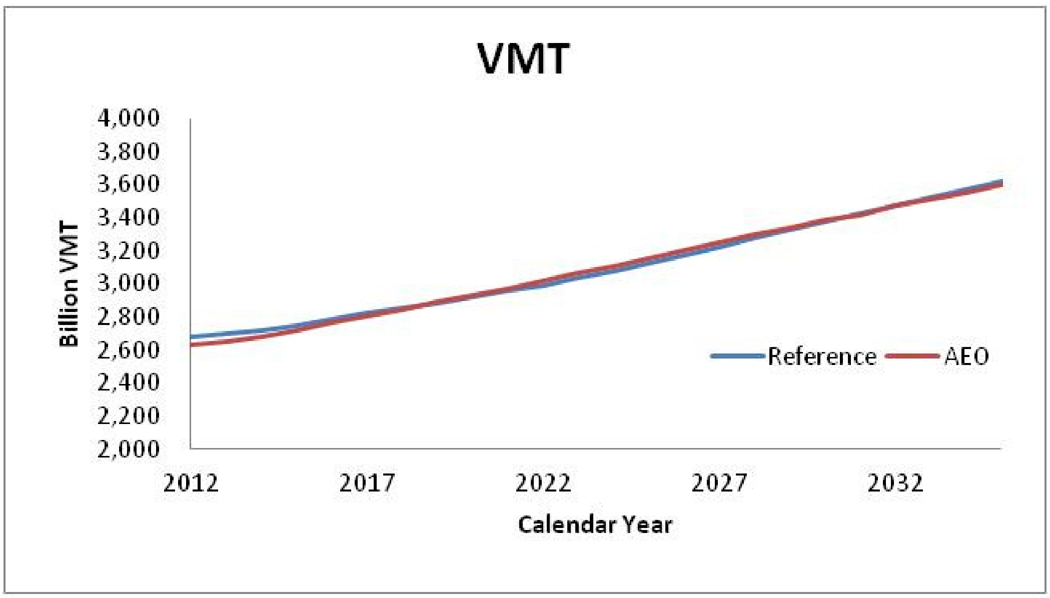

Figure 4-1 Comparison of AEO and Projected VMT

4.2.5 Accounting for the fuel economy rebound effect

The rebound effect refers to the increase in vehicle use that results when an increase in fuel efficiency lowers the cost per mile of driving, which can encourage people to drive more. Because this additional driving results in some fuel consumption and emissions, it results in smaller fuel savings and emissions reductions than would otherwise have resulted from the final standards. Thus the magnitude of the rebound effect is one determinant of the actual fuel savings and emission reductions that are likely to result from adopting stricter fuel economy

[w] See note **Error! Bookmark not defined.** above.

or GHG emissions standards, and is an important parameter affecting EPA's and NHTSA's evaluation of standards for future model years.[x]

The fuel economy rebound effect is measured directly by estimating the change in vehicle use, often expressed in terms of vehicle miles traveled (VMT), that results from a change in vehicle fuel efficiency.[y] However, analysts commonly measure the rebound effect indirectly, by estimating the change in vehicle use that results from a change in fuel cost per mile driven, which depends on both vehicle fuel efficiency and fuel prices.[z] When expressed as positive percentages, the elasticities of vehicle use with respect to fuel efficiency or per-mile fuel costs give the percentage increase in vehicle use that results from a one percent increase in fuel efficiency, or a one percent reduction in fuel cost per mile. For example, a 10 percent rebound effect means that a 10 percent increase in fuel efficiency or a 10 percent decrease in fuel cost per mile is expected to result in a 1 percent increase in vehicle use.

The fuel economy rebound effect for light-duty vehicles has been the subject of a large number of studies since the early 1980s. Although these studies have reported a wide range of estimates of its exact magnitude, they generally conclude that a significant rebound effect occurs when the cost per mile of driving decreases.[aa] The most common approach to estimating its magnitude has been to analyze household survey data on vehicle use, fuel consumption, fuel prices (often obtained from external sources), and other variables that influence travel demand. Other studies have relied on annual aggregate U.S. data. Finally, more recent studies have used annual data from individual states.[bb]

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[x] The rebound effect discussed in this section refers solely to the effect of increased fuel efficiency on vehicle use, which has traditionally been referred to as the "fuel economy rebound effect." More recently, some authors have referred to the fuel economy rebound effect as the "VMT rebound effect," which helps distinguish it from other rebound effects that could potentially impact the fuel savings and emissions reductions from our standards such as the "indirect rebound effect," which occurs when buyers of vehicles with improved fuel economy spend money they save on fuel purchases to buy other products and services that consume or use energy. The discussion in this section exclusively addresses the fuel economy rebound effect as traditionally defined, and uses this term throughout. The agencies received one comment on the proposed rulemaking suggesting that the agencies should attempt to quantify the indirect rebound effect; see preamble III.H.4 for a discussion of this topic.

[y] Vehicle fuel efficiency is more often measured in terms of fuel consumption (gallons per mile) rather than fuel economy (miles per gallon) in rebound estimates.

[z] Fuel cost per mile is equal to the price of fuel in dollars per gallon divided by fuel economy in miles per gallon (or multiplied by fuel consumption in gallons per mile), so this figure declines when a vehicle's fuel efficiency increases.

[aa] Some studies estimate that the long-run rebound effect is significantly larger than the immediate response to increased fuel efficiency. Although their estimates of the adjustment period required for the rebound effect to reach its long-run magnitude vary, this long-run effect could be more appropriate for evaluating the fuel savings and emissions reductions resulting from stricter standards that would apply throughout the lifetime of future model year vehicles.

[bb] In effect, these studies treat U.S. states as a data "panel" by applying appropriate estimation procedures to data consisting of each year's average values of these variables for the separate states.

This section surveys these previous studies, summarizes recent work on the rebound effect,[13] and explains the basis for the 10 percent rebound effect EPA and NHTSA are using in this rulemaking.

4.2.5.1 Summary of historical literature on rebound effect

It is important to note that a majority of the studies previously conducted on the rebound effect rely on data from the 1950-1990s. While these older studies provide valuable information on the potential magnitude of the rebound effect, studies that include more recent information (*e.g.*, data within the last decade) may provide more reliable estimates of how this rule will affect future driving behavior. Therefore, the more recent studies have been described in more detail in Section 4.2.5.2 below.

Estimates based on aggregate U.S. vehicle travel data published by the U.S. Department of Transportation, Federal Highway Administration, covering the period from roughly 1950 to 1990, have found long-run rebound effects on the order of 10-30 percent. Some of these studies are summarized in the following table.

Table 4-6 Estimates of the Rebound Effect Using U.S. Aggregate Time-Series Data on Vehicle Travel[1]

AUTHOR (YEAR)	SHORT-RUN	LONG-RUN	TIME PERIOD
Mayo & Mathis (1988)	22%	26%	1958-84
Gately (1992)	9%	9%	1966-88
Greene (1992)	Linear 5-19% Log-linear 13%	Linear 5-19% Log-linear 13%	1957-89
Jones (1992)	13%	30%	1957-89
Schimek (1996)	5-7%	21-29%	1950-94

[1] Source: Sorrell and Dimitropolous (2007) table 4.6.

Table 4-7 Estimates of the Rebound Effect Using U.S. State Level Data[1]

AUTHOR (YEAR)	SHORT-RUN	LONG-RUN	TIME PERIOD
Haughton & Sarkar (1996)	9-16%	22%	1973-1992
Small and Van Dender (2005 and 2007a)	4.5% 2.2%	22.2% 10.7%	1966-2001 1997-2001
Hymel, Small and Van Dender (2010)	4.7% 4.8%	24.1% 15.9%	1966-2004 1984-2004

[1] Source: Sorrell and Dimitropolous (2007) table 4.7 and the agencies' addition of recent work by Small and Van Dender (2007a) and Hymel, Small, and Van Dender (2010) discussed in section 4.2.5.2.

While studies using national (Table 4-6) and state level (Table 4-7) data have found relatively consistent long-run estimates of the rebound effect, household surveys display more variability (Table 4-8). One explanation is that these studies consistently find that the magnitude of the rebound effect differs according to the number of vehicles a household owns, and the average number of vehicles owned per household differs among the surveys used to derive these estimates. Still another possibility is that it is difficult to distinguish the impact of residential density on vehicle use from that of fuel prices, since households in urban areas are likely to face higher fuel prices.[14]

Table 4-8 Estimates of the Rebound Effect Using U.S. Survey Data[1]

Author (year)	**Short-Run**	**Long-Run**	**Time Period**
Goldberg (1996)	0%		CES 1984-90
Greene, Kahn, and Gibson (1999a)		23%	EIA RTECS 1979-1994
Pickrell & Schimek (1999)		4-34%	NPTS 1995 Single year
Puller & Greening (1999)	49%		CES 1980-90 Single year, cross-sectional
West (2004)	87%		CES 1997 Single year

[1] Source: Sorrell and Dimitropolous (2007) table 4.8 and the agencies' addition of Pickrell & Schimek (1999).

It is important to note that some of these studies actually quantify the price elasticity of gasoline demand (*e.g.*, Puller & Greening[15]) or the elasticity of VMT with respect to the price of gasoline (*e.g.*, Pickrell & Schimek), rather than the elasticity of VMT with respect to fuel efficiency or the fuel cost per mile of driving. These latter measures more closely match the definition of the fuel economy rebound effect. In fact, most studies cited above do not estimate the direct measure of the fuel economy rebound effect (*i.e.*, the increase in VMT attributable to an increase in fuel efficiency). This topic is discussed in more detail in Section 4.2.5.2.

Another important distinction among studies of the rebound effect is whether they assume that the effect is constant, or varies over time in response to the absolute levels of fuel costs, personal income, or household vehicle ownership. Most studies using aggregate annual data for the U.S. assume a constant rebound effect, although some of these studies test whether the effect can vary as changes in retail fuel prices or average fuel efficiency alter fuel cost per mile driven. Many studies using household survey data estimate significantly different rebound effects for households owning varying numbers of vehicles, with most finding that the rebound effect is larger among households that own more vehicles.[cc] Finally,

[cc] Six of the household survey studies evaluated in Table 4-9 found that the rebound effect varies in relation to the number of household vehicles. Of those six studies, four found that the rebound effect rises with higher vehicle ownership, and two found that it declines. The four studies with rebound estimates that increase with higher household vehicle ownership are: Greene, David L., and Patricia S. Hu, "The Influence of the Price of

one recent study using state-level data concludes that the rebound effect varies directly in response to changes in personal income and the degree of urbanization of U.S. cities, as well as fuel costs.

In order to provide a more comprehensive overview of previous estimates of the rebound effect, NHTSA reviewed 22 studies of the rebound effect conducted from 1983 through 2005. The agency then performed a detailed analysis of the 66 separate estimates of the long-run rebound effect reported in these studies, which is summarized in Table 4-9 below.[dd] As the table indicates, these 66 estimates of the long-run rebound effect range from as low as 7 percent to as high as 75 percent, with a mean value of 23 percent. Limiting the sample to 50 estimates reported in the 17 published studies of the rebound effect yields the same range, but a slightly higher mean estimate (24 percent).

The type of data used and authors' assumption about whether the rebound effect varies over time have important effects on its estimated magnitude. The 34 estimates derived from analysis of U.S. annual time-series data produce a mean estimate of 18 percent for the long-run rebound effect, while the mean of 23 estimates based on household survey data is considerably larger (31 percent), and the mean of 9 estimates based on state data (25 percent) is close to that for the entire sample. The 37 estimates assuming a constant rebound effect produce a mean of 23 percent, identical to the mean of the 29 estimates reported in studies that allowed the rebound effect to vary in response to fuel prices, vehicle ownership, or household income.

Table 4-9 Summary Statistics for Estimates of the Rebound Effect

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Gasoline on Vehicle Use in Multivehicle Households," *Transportation Research Record* 988, pp. 19-24 (Docket EPA-HQ-OAR-2010-0799); Hensher, David A., Frank W. Milthorpe, and Nariida C. Smith, "The Demand for Vehicle Use in the Urban Household Sector: Theory and Empirical Evidence," *Journal of Transport Economics and Policy*, 24:2 (1990), pp. 119-137 (Docket EPA-HQ-OAR-2010-0799); Walls, Margaret A, Alan J. Krupnick, and H. S. Hood, "Estimating the Demand for Vehicle-Miles Traveled Using Household Survey Data: Results from the 1990 Nationwide Personal Transportation Survey," Discussion Paper ENR 93-25, Energy and Natural Resources Division, Resources for the Future, Washington, D.C., 1993; and West, Rachel, and Don Pickrell, "Factors Affecting Vehicle Use in Multiple-Vehicle Households," 2009 National Household Travel Survey Workshop, June 2011, http://onlinepubs.trb.org/onlinepubs/conferences/2011/NHTS1/West.pdf (Docket EPA-HQ-OAR-2010-0799). The two studies with rebound estimates that decrease with higher household vehicle ownership are Mannering, Fred L. and Clifford Winston, "A Dynamic Empirical Analysis of Household Vehicle Ownership and Utilization, *Rand Journal of Economics* 16:2 (1985), pp. 215-236 (Docket EPA-HQ-OAR-2010-0799), and Greene, David L., James R. Kahn, and Robert C. Gibson, "Fuel Economy Rebound Effect for Household Vehicles," *The Energy Journal*, 20:3 (1999), 1-21 (Docket EPA-HQ-OAR-2010-0799) (note that the latter showed virtually no difference in the rebound effect as households went from 1 to 2, a moderate decline from 2 to 3 vehicles, and a slight increase from 3 to 4 vehicles; on balance, the rebound estimate for households with 4 vehicles was slightly lower than for households with 1 or 2 vehicles).

[dd] In some cases, NHTSA derived estimates of the overall rebound effect from more detailed results reported in the studies. For example, where studies estimated different rebound effects for households owning different numbers of vehicles but did not report an overall value, the agency computed a weighted average of the reported values using the distribution of households among vehicle ownership categories.

Category of Estimates	Number of Studies	Number of Estimates	Range		Distribution		
			Low	High	Median	Mean	Std. Dev.
All Estimates	22	66	7%	75%	22%	23%	14%
Published Estimates	17	50	7%	75%	22%	24%	14%
U.S. Time-Series Data	7	34	7%	45%	14%	18%	9%
Household Survey Data	13	23	9%	75%	31%	31%	16%
Pooled U.S. State Data	2	9	8%	58%	22%	25%	14%
Constant Rebound Effect (1)	15	37	7%	75%	20%	23%	16%
Variable Rebound Effect: (1)	10	29	10%	45%	23%	23%	10%

4.2.5.2 Summary of recent studies and analyses of the rebound effect

More recent studies published between 2007 and 2010 indicate that the rebound effect has decreased over time as incomes have risen and, until recently, fuel costs as a share of total monetary travel costs have generally decreased.[ee] One theoretical argument for why the rebound effect should vary over time is that the responsiveness to the fuel cost of driving will be larger when it is a larger proportion of the total cost of driving. For example, as incomes rise, the responsiveness to the fuel cost per mile of driving will decrease if people view the time cost of driving – which is likely to be related to their income levels – as a larger component of the total cost.

Small and Van Dender combined time series data for each of the 50 States and the District of Columbia to estimate the rebound effect, allowing the magnitude of the rebound to vary over time.[16] For the time period from 1966-2001, their study found a long-run rebound effect of 22.2 percent, which is consistent with previously published studies. But for the most recent five year period (1997-2001), the long-run rebound effect decreased to 10.7 percent. Furthermore, when the authors updated their estimates with data through 2004, the long-run rebound effect for the most recent five year period (2000-2004) dropped to 6 percent.[17] Finally, when the Small methodology was used to project the future rebound effect, estimates of the rebound effect throughout 2010-2030 were below 6 percent given a range of future gasoline price and income projections.[18]

In 2010, Hymel, Small and Van Dender extended the Small and Van Dender model by adding congestion as an endogenous variable.[19] Although controlling for congestion significantly increased their estimates of the rebound effect, Hymel, Small and Van Dender

[ee] While real gasoline prices have varied over time, fuel costs (which reflect both fuel prices and fuel efficiency) as a share of total vehicle operating costs declined substantially from the mid-1970s until the mid-2000s when the share increased modestly (see Greene (2012)). Note that two studies discussed in this section, Small and Van Dender (2007) and Hymel, Small, and Van Dender (2010), find that the rebound effect is more strongly dependent on income than on fuel costs. A third study, Greene (2012), did not directly test the effect of fuel costs on the rebound effect, but found evidence supporting the effect of income. Several other studies have shown that the rebound effect rises with household vehicle ownership (see section 4.2.5.1), which has generally increased with income.

also found that the rebound effect was declining over time. For the time period from 1966-2004, they estimated a long-run rebound effect of 24 percent, while for 2004 they estimated a long-run rebound effect of 13 percent.

Research conducted by David Greene in 2008-2009 under contract with EPA further appears to support the theory that the magnitude of the rebound effect is declining over time and may be as low as zero.[20] Over the entire time period analyzed (1966-2007), Greene found that fuel prices had a statistically significant impact on VMT, while fuel efficiency did not, which is similar to Small and Van Dender's prior finding. When Small and Van Dender tested whether the elasticity of vehicle travel with respect to the price of fuel was equal to the elasticity with respect to the rate of fuel consumption (gallons per mile), they found that the data could not reject this hypothesis. Therefore, Small and Van Dender estimated the rebound effect as the elasticity of travel with respect to fuel cost per mile. In contrast, Greene's research showed that the hypothesis of equal elasticities for gasoline prices and fuel efficiency can be rejected. In spite of this result, Greene also tested Small and Van Dender's formulation which allows the elasticity of fuel cost per mile to decrease with increasing per capita income. The results of estimation using national time series data confirmed the results obtained by Small and Van Dender using a time series of state level data. When using Greene's preferred functional form, the projected rebound effect is approximately 12 percent in 2008, and drops to 10 percent in 2020 and to 9 percent in 2030.

Since there has been little variation in fuel efficiency in the data over time, isolating the impact of fuel efficiency on VMT can be difficult using econometric analysis of historical data. Therefore, studies that estimate the rebound effect using time-series data often examine the impact of gasoline prices on VMT, or the combined impact of both gasoline prices and fuel efficiency on VMT, as discussed above. However, these studies may overstate the potential impact of the rebound effect resulting from this rule, if people are more responsive to changes in gasoline prices than to changes in fuel efficiency itself. Recent work conducted by Kenneth Gillingham included an estimate of the elasticity of VMT with respect to the price of gasoline of -0.17, while his corresponding estimate of the elasticity of VMT with respect to fuel economy was only 0.05.[21] While this research pertains specifically to California, this finding suggests that the common assumption that consumers respond similarly to changes in gasoline prices and changes in fuel efficiency may overstate the magnitude of the rebound effect. The agencies stated in the draft TSD accompanying the NPRM that more research is needed in this area, and sought comment on this aspect of the rebound effect. No comments were received on this specific issue.

Another question discussed by Gillingham is whether consumers actually respond the same way to an increase in the cost of driving compared to a decrease in the cost of driving. There is some evidence in the literature that consumers are more responsive to an increase in prices than to a decrease in prices. At the aggregate level, Dargay & Gately and Sentenac-Chemin have shown that demand for transportation fuel is asymmetric.[22,23] In other words, given the same size change in prices, the response to a decrease in gasoline price is smaller than the response to an increase in gasoline price. Gately has shown that the response to an increase in oil prices can be on the order of five times larger than the response to a price decrease.[24] Furthermore, Dargay & Gately and Sentenac-Chemin find evidence that consumers respond more to a large shock than a small, gradual change in fuel prices. Since these standards would decrease the cost of driving gradually over time, it is possible that the rebound effect would be much smaller than some of the historical estimates included in the literature. Although these types of asymmetric responses have been noted at the aggregate level on oil and gasoline consumption, little research has been done on these same phenomena in the context of changes in vehicle fuel efficiency and the resulting rebound effect. The agencies stated in the draft TSD accompanying the NPRM that more research in this area is also important, and sought comment on this aspect of the rebound effect. No comments were received on this specific issue.

Other recent studies came to our attention after we finalized our estimate of the rebound effect used in the analysis for our final rules.[25] We will examine these and other new studies on this topic for future rulemakings.

4.2.5.3 Basis for rebound effect used by EPA and NHTSA in this rule

As the preceding discussion indicates, there is a wide range of estimates for both the historical magnitude of the rebound effect and its projected future value, and there is some evidence that the magnitude of the rebound effect appears to be declining over time. Nevertheless, NHTSA requires a single point estimate for the rebound effect as an input to its analysis, although a range of estimates can be used to test the sensitivity to uncertainty about its exact magnitude. Based on a combination of historical estimates of the rebound effect and more recent analyses, an estimate of 10 percent for the rebound effect was used for this final rule (*i.e.*, we assume a 10 percent decrease in fuel cost per mile from our standards would result in a 1 percent increase in VMT). EPA uses a range of 0–20 percent for sensitivity testing, while NHTSA uses 5-20 percent.

As Table 4-6, Table 4-7, Table 4-8, and Table 4-9 indicate, the 10 percent figure is on the low end of the range reported in previous research. However, some recent research – particularly that conducted by Hymel, Small and Van Dender, Small and Van Dender, and Greene – reports evidence that the magnitude of the rebound effect is likely to be declining over time. Furthermore, for the reasons described in section 4.2.5.2, historical estimates of the rebound effect may overstate the effect of a gradual decrease in the cost of driving due to our standards.

As a consequence, the agencies concluded that a value on the low end of the historical estimates reported in Table 4-6, Table 4-7, Table 4-8, and Table 4-9 is likely to provide a more reliable estimate of its magnitude during the future period spanned by the agencies' analyses of the impacts of this rulemaking. The 10 percent estimate lies within the 10-30 percent range of estimates for the historical rebound effect reported in most research, and at the upper end of the 5-10 percent range of estimates for the future rebound effect reported in the recent studies by Small and Greene. In summary, the 10 percent value was not derived from a single point estimate from a particular study, but instead represents a reasonable compromise between historical estimates of the rebound effect and forecasts of its projected future value.

In their proposed rules, the agencies sought comment and new data on alternative methods for estimating the rebound effect over the period that our rulemaking would go into effect. In particular, the agencies sought comment and data on the potential that the rebound effect could be lower than the estimates in the literature if drivers respond more to changes in fuel prices than fuel efficiency, price rises than price decreases, and price shocks than gradual price changes (as discussed in section 4.2.5.2). EPA also sought comment and data on the rebound effect for consumers driving vehicles powered by grid electricity. We believe more research on these topics is important. During the public comment period, the agencies did not receive any comments on these topics and the few comments we did receive on the fuel economy rebound effect did not provide persuasive new evidence. Hence, EPA and NHTSA have elected to continue to use the 10 percent estimate of the rebound effect in the analyses supporting this final rulemaking. The agencies will review the estimate of the rebound effect again for any future rulemakings based on the best available information at that time.

4.2.6 Benefits from additional driving

The increase in travel associated with the rebound effect produces additional benefits to vehicle owners, which reflect the value to drivers and other vehicle occupants of the added (or more desirable) social and economic opportunities that become accessible with additional travel. The analysis estimates the economic benefits from increased rebound-effect driving as the sum of fuel costs drivers incur plus the consumer surplus they receive from the additional accessibility it provides. As evidenced by the fact that drivers elect to make more frequent or longer trips when the cost of driving declines, the benefits from this added travel exceed drivers' added outlays for the fuel consumed. The amount by which the benefits from this increased driving travel exceed its increased fuel costs measures the net benefits drivers receive from the additional travel, usually are referred to as increased consumer surplus.

The agencies' analysis estimates the economic value of the increased consumer surplus provided by added driving using the conventional approximation, which is one half of the product of the decline in vehicle operating costs per vehicle-mile and the resulting increase in the annual number of miles driven. Because it depends on the extent of improvement in fuel economy, the value of benefits from increased vehicle use changes by model year and varies among alternative standards. Under even those alternatives that would impose the highest standards, however, the magnitude of the consumer surplus from additional vehicle use represents a small fraction of this benefit.

4.2.7 Added costs from increased vehicle use

While it provides some benefits to drivers, increased vehicle use associated with the rebound effect also contributes to increased traffic congestion, motor vehicle accidents, and highway noise. Depending on how the additional travel is distributed over the day and on where it takes place, additional vehicle use can contribute to traffic congestion and delays by increasing traffic volumes on facilities that are already heavily traveled. These added delays impose higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses. Because drivers do not take these added costs into account in deciding when and where to travel, they must be accounted for separately as a cost of the added driving associated with the rebound effect.

Increased vehicle use due to the rebound effect may also increase the costs associated with traffic accidents. Drivers may take account of the potential costs they (and their passengers) face from the possibility of being involved in an accident when they decide to make additional trips. However, they probably do not consider all of the potential costs they impose on occupants of other vehicles and on pedestrians when accidents occur. Thus any increase in these "external" accident costs must be considered as another cost of additional rebound-effect driving. Like increased delay costs, any increase in these external accident costs caused by added driving is likely to depend on the traffic conditions under which it takes place, since accidents are more frequent in heavier traffic (although their severity may be reduced by the slower speeds at which heavier traffic typically moves).

Finally, added vehicle use from the rebound effect may also increase traffic noise. Noise generated by vehicles causes inconvenience, irritation, and potentially even discomfort to occupants of other vehicles, to pedestrians and other bystanders, and to residents or occupants of surrounding property. Because these effects are unlikely to be taken into account by the drivers whose vehicles contribute to traffic noise, they represent additional externalities associated with motor vehicle use. Although there is considerable uncertainty in measuring their value, any increase in the economic costs of traffic noise resulting from added vehicle use must be included together with other increased external costs from the rebound effect. To estimate the increased external costs caused by added driving due to the rebound effect, EPA and NHTSA rely on estimates of congestion, accident, and noise costs caused by automobiles and light trucks developed previously by the Federal Highway Administration.[26] NHTSA employed these estimates previously in its analysis accompanying the MY 2011 final rule, and the agencies jointly applied them in the MYs 2012-2016 rulemaking and in the proposal to this rulemaking, and the agencies continue to find them appropriate for this final rule. The values are intended to measure the increases in costs (or "marginal" external costs) from added congestion, property damages and injuries in traffic accidents, and noise levels caused by automobiles and light trucks that are borne by persons other than their drivers and occupants.

Updated to 2010 dollars, FHWA's "Middle" estimates for marginal congestion, accident, and noise costs caused by automobile use amount to 5.6 cents, 2.4 cents, and 0.1 cents per vehicle-mile (for a total of 8.1 cents per mile), while those for pickup trucks and vans are 5.1 cents, 2.7 cents, and 0.1 cents per vehicle-mile (for a total of 7.8 cents per mile).[27, ff] These costs are multiplied by the mileage increases attributable to the rebound effect to yield the estimated increases in congestion, accident, and noise externality costs during future years.

[ff] The Federal Highway Administration's estimates of these costs agree closely with some other recent estimates. For example, recent published research conducted by Resources for the Future (RFF) estimates marginal congestion and external accident costs for increased light-duty vehicle use in the U.S. to be 3.5 and 3.0 cents per vehicle-mile in year-2002 dollars. *See* Ian W.H. Parry and Kenneth A. Small, "Does Britain or the U.S. Have the Right Gasoline Tax?" Discussion Paper 02-12, Resources for the Future, 19 and Table 1 (March 2002). *Available at* http://www.rff.org/rff/Documents/RFF-DP-02-12.pdf (last accessed May 30, 2012).

4.2.8 Petroleum and energy security impacts

The final standards for MYs 2017-2025 will reduce fuel consumption and GHG emissions in light-duty vehicles, which will result in improved fuel efficiency and, in turn, help to reduce U.S. petroleum imports. A reduction of U.S. petroleum imports reduces both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S. This reduction in the expected future economic costs associated with these risks provides a measure of value of improved U.S. energy security resulting from lower petroleum imports. This section summarizes the agencies' estimates of U.S. oil import reductions and energy security benefits of the program. Additional discussion of this issue can be found in Section III.H and Section IV.C.3 of the preamble.

4.2.8.1 Impact on U.S. petroleum imports

In 2011, U.S. petroleum import expenditures represented 16 percent of total U.S. imports of all goods and services.[28,29] In 2011, the United States imported 45 percent of the petroleum it consumed[30], while the transportation sector accounted for 70 percent of total U.S. petroleum consumption.[31] These figures compare to approximately 37 percent of U.S. petroleum supplied by imports and 55 percent of total petroleum consumed by the nation's transportation sector during 1975.[32] Requiring improved fuel economy and lower-GHG vehicle technology in the U.S. is expected to lower U.S. petroleum imports.

Based on analysis of historical and projected future variation in U.S. petroleum consumption and imports, EPA and NHTSA estimate that approximately 50 percent of the reduction in fuel consumption resulting from adopting improved GHG emission and fuel efficiency standards is likely to be reflected in lower U.S. imports of refined fuel, while the remaining 50 percent is expected to be reflected in reduced domestic fuel refining.[gg] Of this latter figure, 90 percent is anticipated to reduce U.S. imports of crude petroleum for use as a refinery feedstock, while the remaining 10 percent is expected to reduce U.S. domestic production of crude petroleum.[hh] Thus, on balance, each gallon of fuel saved as a consequence of our final standards is anticipated to reduce total U.S. imports of petroleum by 0.95 gallons.[ii]

[gg] Differences in forecasted annual U.S. imports of crude petroleum and refined products among the Reference, High Oil Price, and Low Oil Price scenarios analyzed in EIA's Annual Energy Outlook 2011 range from 35-74 percent of differences in projected annual gasoline and diesel fuel consumption in the U.S. These differences average 53 percent over the forecast period spanned by AEO 2011.

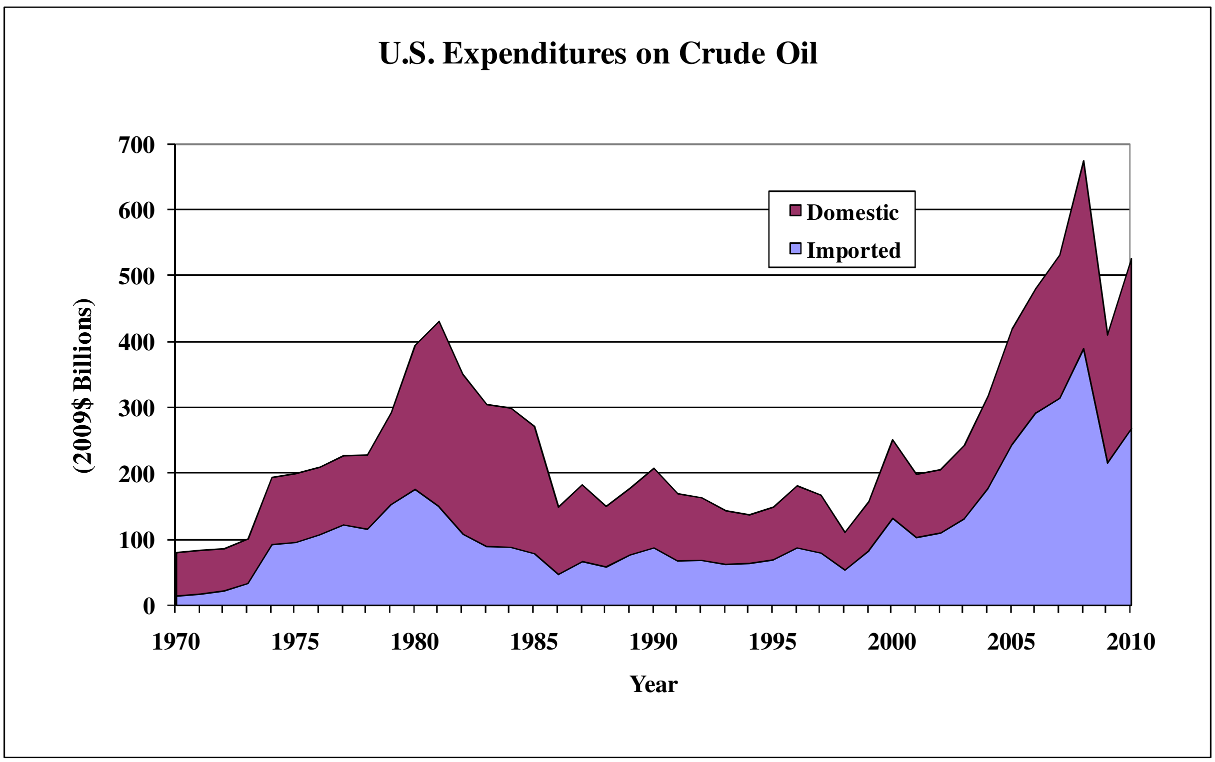
[hh] Differences in forecasted annual U.S. imports of crude petroleum among the Reference, High Oil Price, and Low Oil Price scenarios analyzed in EIA's Annual Energy Outlook 2011 range from 67-104 percent of differences in total U.S. refining of crude petroleum, and average 90 percent over the forecast period spanned by AEO 2011.

[ii] This figure is calculated as 0.50 + 0.50*0.9 = 0.50 + 0.45 = 0.95.

4.2.8.2 Background on U.S. energy security

U.S. energy security is broadly defined as protecting the U.S. economy against circumstances that threaten significant short- and long-term increases in energy costs or interruptions in energy supplies. Most discussions of U.S. energy security focus on the economic costs of U.S. dependence on oil imports, and particularly on U.S. reliance on oil imported from potentially unstable sources. In addition, oil exporters have the ability to raise the price of oil by exerting monopoly power through the mechanism of a cartel, the Organization of Petroleum Exporting Countries (OPEC). These factors contribute to the vulnerability of the U.S. economy to episodic oil supply shocks and price spikes. In 2010, total U.S. imports of crude oil, including those from OPEC nations as well as other sources, were $271 billion (in 2010$)[33] (see Figure 4-2).

Figure 4-2 U.S. Expenditures on Crude Oil from 1970 through 2010[jj]



A significant effect of the MY 2017-2025 fuel economy and GHG standards (as well as the MY 2012-2016 light-duty vehicle standards and the MY 2014-2018 standards for

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Source for historical data: EIA Annual Energy Review, various editions. For recent historical and forecasted data: EIA Annual Energy Outlook (AEO) 2011 Reference Case.

medium- and heavy-duty vehicles) will be to reduce consumption of transportation fuels in the U.S. This will in turn reduce U.S. oil imports, which lowers both financial and strategic risks associated with potential disruptions in supply or sudden increases in the price of petroleum. For this rulemaking, an "oil import premium" approach is utilized to estimate energy security-related costs of importing petroleum into the U.S. Specifically, the oil import premium measures the expected economic value of costs that are not reflected in the market price of petroleum, and that are expected to change in response to an incremental change in the level of U.S. oil imports.

4.2.8.3 Methodology used to estimate U.S. energy security benefits

In order to understand the energy security implications of reducing U.S. oil imports, EPA has worked with Oak Ridge National Laboratory (ORNL), which has developed approaches for evaluating the social costs and energy security implications of oil use. The energy security estimates provided below are based upon a methodology developed in a peer-reviewed study entitled, "*The Energy Security Benefits of Reduced Oil Use, 2006-2015*," completed in March 2008. This study is included as part of the docket for this rulemaking.[34]

When conducting the analysis for EPA and NHTSA for purposes of analyzing our final standards, ORNL considered the full cost of importing petroleum into the U.S. The full economic cost is defined to include two components in addition to the purchase price of petroleum itself. These are: (1) the higher costs for oil imports resulting from the effect of U.S. import demand on the world oil price and on OPEC market power (*i.e.*, the "demand" or "monopsony" costs); and (2) the risk of reductions in U.S. economic output and disruption of the U.S. economy caused by sudden disruptions in the supply of imported oil to the U.S. (*i.e.*, "macroeconomic disruption and adjustment costs"). Costs associated with U.S. military expenditures to help secure stable oil supply from volatile regions of the world were not included in this analysis, because attributing costs for military operations to specific missions or activities is difficult and the majority of the literature indicates that it is uncertain if merely reducing (rather than entirely eliminating) reliance on imported oil would lead to measurable changes in U.S. military expenditures (as discussed further).

For this analysis, ORNL estimated energy security premiums by incorporating the AEO 2012 Early Release oil price forecasts and market trends, which was the most recent data available at the time the analyses for the final rules were conducted. Energy security premiums for the years 2020, 2025, 2030, and 2035 and beyond are presented in Table 4-11, as well as a breakdown of the components of the energy security premiums for each of these years.[kk] AEO 2012 Early Release projects energy market trends and values out only to 2035. The agencies assume that energy security premium estimates post-2035 will remain constant, consistent with a flat extrapolation of oil prices from AEO 2012 after 2035.

[kk] AEO 2012 Early Release forecasts energy market trends and values only to 2035. The energy security premium estimates post-2035 were assumed to be the 2035 estimate.

Based on the ORNL analysis, the total oil security premium initially declines slightly through 2020, and then gradually rises over the future as a result of changing factors such as the world oil price, global supply/demand balances, U.S. oil imports and consumption, and U.S. GDP (i.e., the size of economy at risk to oil shocks). The principal factors are steadily rising world oil prices and a growing economy, but other effects interact. From 2020 to 2030, the macroeconomic disruption and adjustment component rises by 14 percent. This is over a period where projected average real world oil prices rise 10 per cent and U.S. GDP, the size of the economy potentially at risk to oil shocks, grows 28 percent. U.S. oil import quantities decline through 2020, but are steady thereafter through 2035, while total domestic oil consumption still rises modestly (by 3 percent) despite higher prices. The value share of oil in GDP stays fairly high; it is still at 3.9 percent by 2030 (vs. 4.5 percent in 2020).

The components of the energy security premiums and their values are discussed below, as well as how we generally applied them in our respective analyses of the final standards. Section III.H and Section IV.C.3 of the preamble contains a detailed discussion of how the monopsony and macroeconomic disruption/adjustment components were treated in the analysis of our final standards.

Table 4-10 Energy Security Premiums in Selected Years (2010$/Barrel)[1]

	Monopsony	Macroeconomic Disruption/Adjustment Costs	Total
2020	\$10.02 (\$3.35 - \$17.09)	\$7.63 (\$3.71 - \$11.00)	\$17.64 (\$9.83 - \$25.00)
2025	\$9.77 (\$3.25 - \$16.69)	\$8.26 (\$4.03 - \$11.92)	\$18.03 (\$10.15 - \$25.47)
2030	\$9.28 (\$3.10 - \$18.03)	\$8.77 (\$4.33 - \$12.60)	\$18.05 (\$10.29 - \$25.20)
2035+	\$9.73 (\$3.24 - \$16.68)	\$9.46 (\$4.72 - \$13.61)	\$19.19 (\$10.94 - \$26.78)

[1]The main values represent the mid-point of the ranges of the values presented in the parentheses.

The Defour Group commented that there is no relationship between the energy security benefits of the U.S. and reduced oil consumption by the U.S., since the world economies are all tied together, thus calling into question estimates of the energy security benefits of these rules. Moreover, the Defour Group believes there is too much uncertainty in generating energy security premiums, and asserted that the energy security premiums are not a credible approach to providing estimates of energy security benefits of the rules.

The EPA sponsored an extensive peer review of the methodology on which the energy security benefits for these rules is based.[35] The methodology of estimating the monopsony and macroeconomic effects for estimating the energy security benefits of particular actions, policies, and rules has been well documented and is well accepted by the energy security community.[36] Thus, the agencies continue to use the current methodology for estimating the monopsony and macroeconomic effects for estimating the energy security benefits of our rules.

4.2.8.4 Monopsony Effect

The first component of the full economic costs of importing petroleum into the U.S. follows from the effect of U.S. import demand on the world oil price over the long-run. Because the U.S. purchases a sufficiently large percentage of foreign oil supplies, it exercises "monopsony power" in the global petroleum market. This means that increases in U.S. petroleum demand can cause the world price of crude oil to rise, and conversely, that reduced U.S. petroleum demand can reduce the world price of crude oil.

Thus, one benefit to the U.S. of reducing U.S. oil purchases, due both to reductions in overall energy consumption in transportation and substitution of transportation fuels derived from non-petroleum sources is the potential decrease in the total dollar value of U.S. crude oil purchases. Because lower U.S. oil purchases reduce the price paid for each barrel, the decline in the total cost of U.S. petroleum purchases exceeds the savings that would result if the global price for oil remained unchanged. The amount by which it does so – which reflects the effect of U.S. monopsony power over the world oil price – represents the "monopsony" effect of reduced U.S. petroleum consumption.

This "monopsony" effect can be readily illustrated with an example. If the U.S. imports 10 million barrels per day at a world oil price of $50 per barrel, its total daily bill for oil imports is $500 million. If a decrease in U.S. imports to 9 million barrels per day causes the world oil price to drop to $49 per barrel, the daily U.S. oil import bill drops to $441 million (9 million barrels times $49 per barrel). While the world oil price declines by only $1, the resulting decrease in oil purchases equals $59 million per day ($500 million minus $441 million). This is equivalent to an incremental savings of $59 for each barrel by which U.S. oil imports decline ($59 million per day divided by 1 million barrels per day), or $10 more than the newly-decreased world price of $49 per barrel.

This additional $10 per barrel reduction in the "monopsony premium" represents the incremental external benefits to the U.S. associated with the reduction in import payments beyond the savings that would occur if prices remained unchanged. Of course, this additional benefit arises only to the extent that reduction in U.S. oil imports actually affects the world oil price. ORNL estimates this component of the energy security benefit in 2025 to be $9.77 /barrel by which U.S. petroleum imports are reduced, with a range of $3.25 - $16.69/barrel.[ll] Notwithstanding the discussion above, the agencies do not, in fact, include this component of the energy security premium as part of the benefit estimates of our final rules, since it is a

[ll] "Estimating the U.S. Oil Security Premium for the Proposed 2017-2025 Light -Duty Vehicle GHG/Fuel Economy Rule", Paul N. Leiby, Oak Ridge National Laboratory (ORNL), 2012

transfer between the U.S. and oil exporting countries, whose potential climate change damages are accounted for in the agencies' estimate of the social cost of carbon, as explained further in section 4.2.8.7 below and in the preamble Sections III.H.8 and IV.C.3.

4.2.8.5 Macroeconomic Disruption and Adjustment Effect

The second component of the oil import premium, the "macroeconomic disruption and adjustment cost premium", arises from the effect of U.S. oil imports on the expected cost of disruptions in oil supply and resulting increases in oil prices. A sudden increase in oil prices triggered by a disruption in world oil supplies has two main effects: (1) it increases the costs of oil imports in the short run, further expanding the transfer of U.S. wealth to foreign producers, and (2) it can lead to macroeconomic contraction, dislocation and losses in Gross Domestic Product (GDP). ORNL estimates the composite estimate of these two factors that comprise the macroeconomic disruption/adjustment costs premium to be $8.26 /barrel in 2025, with a range of $4.03–11.92/barrel of imported oil reduced. [37] This component of the energy security premium is included in the agencies' estimate of the benefits of the final standards. See more discussion of how the agencies account for the energy security benefits of the rules in Section III.H.8, and Section IV.C.3.

During oil price shocks, the higher price of imported oil causes increased payments for imports from the U.S to oil exporters. This increased claim on U.S. economic output is a loss to the U.S. that is separate from and additional to any reduction in economic output due to the shock. The increased oil payments during shocks are counted as a loss to the degree that the expected price increase is not anticipated and internalized by oil consumers.

Secondly, macroeconomic losses during price shocks reflect both losses in aggregate economic output and "allocative" losses. The former are reductions in the level of output that the U.S. economy can produce by fully utilizing its available resources, while the latter stem from temporary dislocation and underutilization of available resources due to the shock, such as labor unemployment and idle plant capacity. The aggregate output effect, a reduction in "potential" economic output, will persist as long as the price for oil remains elevated. Thus its magnitude depends on the extent and duration of any disruption in the world supply of oil, since these factors determine the extent of the resulting increase in prices for petroleum products, as well as whether and how rapidly these prices return to their pre-disruption levels.

In addition to the aggregate contraction, there are "allocative" or "adjustment" costs associated with dislocations in energy markets. Because supply disruptions and resulting price increases occur suddenly, empirical evidence shows they also impose additional costs on businesses and households for adjusting their use of petroleum and other productive factors more rapidly than if the same price increase had occurred gradually. Dislocation effects include the unemployment of workers and other resources during the time period required for their inter-industry or interregional reallocation, as well as pauses in capital investment due to uncertainty. These adjustments temporarily reduce the level of economic output that can be achieved even below the "potential" output level that would ultimately be reached once the economy's adaptation to higher petroleum prices was complete. The additional costs imposed on businesses and households for making these adjustments reflect their limited ability to adjust prices, output levels, and their use of energy, labor and other inputs quickly and smoothly in response to rapid changes in prices for petroleum products.

Since future disruptions in foreign oil supplies are an uncertain prospect, each of the disruption cost components must be weighted by the probability that the supply of petroleum to the U.S. will actually be disrupted. Thus, the "expected value" of these costs – the product of the probability that a supply disruption will occur and the sum of costs from reduced economic output and the economy's abrupt adjustment to sharply higher petroleum prices – is the relevant measure of their magnitude. Further, when assessing the energy security value of a policy to reduce oil use, only the *change* in these expected costs from potential disruptions that results from the policy is relevant. The expected costs of disruption may change from lowering the normal (*i.e.*, pre-disruption) level of domestic petroleum use and imports, from any induced alteration in the likelihood or size of disruption, or from altering the short-run flexibility in substituting other energy sources or inputs for petroleum use.

In summary, the steps needed to calculate the disruption or security premium are: (1) determine the likelihood of an oil supply disruption in the future; (2) assess the likely impacts of a potential oil supply disruption on the world oil price; (3) assess the impact of the oil price shock on the U.S. economy (in terms of import costs and macroeconomic losses); and (4) determine how these costs are likely to change with the level of U.S. oil imports. The reduction in the expected value of costs and other macroeconomic losses that results from lower oil imports represents the macroeconomic and adjustment cost portion of the oil import premium.

4.2.8.6 Cost of existing U.S. energy security policies

The last often-identified component of the full economic costs of U.S. oil imports is the costs to the U.S. taxpayers of existing U.S. energy security policies. The two primary components of this cost are (1) the expenses associated with maintaining a U.S. military presence – in part to help secure a stable oil supply – in potentially unstable regions of the world; and (2) costs for maintaining the U.S. Strategic Petroleum Reserve (SPR). The SPR is the largest stockpile of government-owned emergency crude oil in the world. Established in the aftermath of the 1973-74 oil embargo, the SPR provides the U.S. a response option should price increases triggered by a disruption in commercial oil supplies threaten the U.S. economy. It also allows the U.S. to meet part of its International Energy Agency obligation to maintain emergency oil stocks, and it provides a national defense fuel reserve.

The agencies recognize that potential national and energy security risks exist due to the possibility of tension over oil supplies. Much of the world's oil and gas supplies are located in countries facing social, economic, and demographic challenges, thus making them even more vulnerable to potential local instability. For example, in 2010 just over 40 percent of world oil supply came from OPEC nations, and the AEO 2012 projections through 2030 show no decline in this share.[mm] Approximately 28 percent of global supply is from Persian Gulf countries alone. As another measure of concentration, of the 137 countries/principalities that export either crude oil or refined petroleum product, the top 12 have recently accounted for over 55 percent of exports.[38] Eight of these countries are members of OPEC, and Russia is ninth.[nn] In a market where even a 1-2 percent supply loss raises prices noticeably, and where a 10 percent supply loss could lead to a significant price shock, this regional concentration is of concern. Historically, the countries of the Middle East have been the source of eight of the ten major world oil disruptions[39] with the ninth originating in Venezuela, an OPEC member.

Because of U.S. dependence on oil, the military could be called on to protect energy resources through such measures as securing shipping lanes from foreign oil fields to avoid economic losses in the U.S. As Lieutenant General (Ret.) Richard Zilmer, commander of U.S. coalition forces in Anbar province in Iraq in 2006-2007, testified at the Philadelphia public hearing in support of the proposed standards: "better gas mileage is simply a matter of national security."[40] Lt. Gen. (Ret.) Zilmer contributed to a report of the Center for Naval Analyses (CNA) that discussed the implications of oil import reductions and energy security.[41] The report focused on changes in the American transportation sector, in terms of fuel efficiency, alternative fuels, and transportation habits that would be needed in order for the U.S. economy to have enough resilience to sustain a drastic disruption in oil supply. Among its findings and recommendations, the report states that "[t]he federal government fuel economy standards have proven to be effective at increasing efficiency and reducing the use of oil...These standards should be supported and strengthened as a means of making our nation more secure." The report states that "[t]he benefits of efficiency are so obvious and sizeable that it is amazing to consider how or why our country has failed to insist on (or at least incentivize) it up to now.¨ Finally, the report states "[w]hile our study focuses on alternative fuels, we repeatedly found the best and most strategically promising alternative to be efficiency."

Part of the goals of a U.S. military presence in the Persian Gulf is to avoid the impacts oil price shocks from a supply cut-off on the U.S. economy. Although CNA did not conduct an economy-wide analysis of an oil supply shock, it did consider the impact of such a shock on one industrial sector that is heavily dependent on petroleum: the trucking transportation industry. CNA then considered a 100% disruption in the flow of oil, lasting 30 days in the Strait of Hormuz. They estimated that such a disruption would have caused losses of $3.3 billion or 2.9 percent of the U.S. trucking industry's output in 2009. According to CNA, this disruption would have caused 37,500 truckers to lose their jobs. This analysis concludes with "[i]f the U.S. – and this industry in particular – could reduce its use of petroleum by 30 percent, the effect of such supply disruptions would be nearly zero." Although CNA's report focused on the trucking sector, the agencies believe that these findings are relevant to this rule since both the heavy-duty and light-duty vehicles in the U.S. are highly dependent upon petroleum.

[mm] "DOE/EIA AEO2012, Table 21. International Liquids Supply and Disposition Summary".
[nn] The other three are Norway, Canada, and the EU, an exporter of product.

It is CNA's view that there are several other strategically important reasons for maintaining a significant military presence in the Middle East beyond protecting oil routes. Therefore, CNA does not necessarily believe that reduced oil consumption would automatically lead to the return of troops stationed in the region.

Moreover, the military itself is heavily dependent on oil. To maintain such military effectiveness and flexibility, the Department of Defense identified in the Quadrennial Defense Review that it is "increasing its use of renewable energy supplies and reducing energy demand to improve operational effectiveness, reduce greenhouse gas emissions in support of U.S. climate change initiatives, and protect the Department from energy price fluctuations."[42] The Department of the Navy has also stated that the Navy and Marine Corps rely far too much on petroleum, which "degrades the strategic position of our country and the tactical performance of our forces. The global supply of oil is finite, it is becoming increasingly difficult to find and exploit, and over time cost continues to rise."[43] In remarks given to the White House Energy Security Summit on April 26, 2011, Deputy Security of Defense William J. Lynn, III noted the direct impact of energy security on military readiness and flexibility. According to Deputy Security Lynn, "Today, energy technology remains a critical element of our military superiority. Addressing energy needs must be a fundamental part of our military planning."[44]

The agencies' analysis of energy security benefits from reducing U.S. oil imports did not include an estimate of potential reductions in costs for maintaining a U.S. military presence to help secure stable oil supply from potentially vulnerable regions of the world because attributing military spending to particular missions or activities is difficult. Many commenters in both written comments and at the agencies' public hearings expressed their belief that these standards will have significant benefits for U.S. energy and national security. A number of commenters, including consumer advocacy and environmental organizations, organizations representing labor, and state and local governments, as well as energy security advocates and numerous private individuals, felt that the agencies should quantify, to the extent possible, a military component of the energy security benefits associated with this rulemaking. These commenters felt that although they understand that the agencies would have difficulties in determining a point estimate of the energy security benefits from reduced military costs as a result of the rule, that even ranges would be useful. The American Petroleum Institute commented that military expenditures will not likely change with a reduction in U.S. oil imports, and therefore should not be included in the assessment of this rulemaking.

However, the agencies have examined methodologies for estimating the military component of the energy security benefits of our rules and have faced two major challenges: "attribution" and "incremental" analysis. The attribution analysis challenge is to determine which military programs and expenditures can properly be attributed to oil supply protection, rather than to some other objective. The incremental analysis challenge is to estimate how much the supply protection costs might vary if U.S. oil use is reduced or eliminated. However, the agencies have reviewed a number of newer studies that attempt to overcome these challenges.[45]

Most commonly, analysts in recent studies estimate substantial military costs associated with the missions of oil supply security and associated contingencies, but avoid estimating specific cost reductions from partial reductions in oil use. Some recent studies seek to update, and in some cases significantly improve, the rigor of analysis. At the low end of the range, the Council on Foreign Relations takes the view that substantial foreign policy-related military missions will remain over the next 20 years, even without the oil security mission. Alternatively, Delucchi and Murphy[46] sought to deduct from the cost of Persian Gulf military programs the costs associated with defending other U.S. interests (that is, interests other than providing more stable domestic oil supply and price to the U.S. economy). Excluding an estimate of cost for missions in the Persian Gulf unrelated to oil, and excluding costs for providing military protection for other countries' oil import security, Delucchi and Murphy estimated military costs for all U.S. domestic oil interests of between $18 and $59 billion in 2004.

In another recent study, RAND[47] considered force reductions and cost savings that could be achieved if oil security were no longer a consideration. Taking two approaches, and guided by post Cold-War force draw downs and by a top-down look at the current U.S. allocation of defense resources, RAND concluded that $75–$91 billion, or 12–15 per cent of the U.S. defense budget in 2009 could be reduced if U.S. dependence on imported oil were eliminated entirely. However, the study also concludes that the reduction in military costs from a partial reduction in the U.S. dependence on imported oil would be minimal. In another study, Stern[48] presents an estimate of military cost for Persian Gulf force projection, addressing the challenge of cost allocation with an activity-based cost method. He used information on actual naval force deployments rather than budgets, focusing on the costs of aircraft carrier deployment. For the 1976–2007 time frame, Stern estimated an average military cost of $212 billion per year and $500 billion for 2007 alone that could be potentially reduced with lower oil imports.

Although these recent studies provide significant, useful insights into the military components of U.S. energy security, they do not provide enough substantive analysis to develop a robust methodology for quantifying the military components of energy security for this rulemaking. Even for studies that provide insight into the attribution of specific missions to the objective of securing international oil production and distribution, they provide little guidance on the degree to which incremental reductions in the U.S. dependence on imported oil would reduce or eliminate those missions or programs. Thus, while the agencies plan to continue to review newer studies and literature to better estimate the military components of U.S. energy security benefits, for this rulemaking the agencies continue to exclude military cost components in our quantified energy security benefits. To summarize, the agencies have been unable to calculate the monetary benefit that the United States will receive from the improvements in national security expected to result from our standards.

An additional potential component of the full economic costs of oil imports is the costs of building and maintaining the SPR. The SPR is clearly related to U.S. oil use and imports. Indeed, a stated purpose of the Energy Policy Conservation Act is “to provide for the creation of a Strategic Petroleum Reserve capable of reducing the impact of severe energy supply interruptions,” a provision enacted following the 1973-74 Arab oil embargo.[oo] However, these costs have not varied historically in response to changes in U.S. oil import levels. Thus although the influence of the SPR on oil price increases resulting from a disruption of U.S oil imports is reflected in the ORNL estimate of the macroeconomic and adjustment cost component of the oil import premium, potential changes in the cost of maintaining the SPR associated with variation in U.S petroleum imports are excluded.

4.2.8.7 Total Energy Security Benefits

Much of the literature on the energy security for the last two decades has routinely combined the monopsony and the macroeconomic disruption components when calculating the total value of the energy security premium. However, in the context of using a global social cost of carbon (SCC) value, the question arises: how should the energy security premium be measured from a global perspective? Monopsony benefits largely represent a reduction in payments by consumers of petroleum products in the United States to foreign oil producers that result from a decrease in the world oil price as the U.S. decreases its petroleum consumption.

Although a reduction in these payments clearly represents a benefit to the U.S. when considered from a domestic perspective, it represents an exactly offsetting loss to petroleum-producing countries. Given the purely redistributive nature of this monopsony effect when viewed from a global perspective, it is excluded in the energy security benefits calculations for this program. The Union of Concerned Scientists recommended that the monopsony benefits of the rules be included in the agencies’ overall estimates of the energy security benefits of their respective rules, since it is a benefit to the U.S. The agencies continue to view energy security from a global perspective, and therefore exclude monopsony benefits to the U.S. since these benefits are offset by losses to foreign oil producers.

In contrast, the other portion of the energy security premium, the U.S. macroeconomic disruption and adjustment cost that arises from U.S. petroleum imports, does not have offsetting impacts outside of the U.S., and is thus included in the energy security benefits estimated for this program. Thus, the agencies have included only the macroeconomic disruption portion of the energy security benefits to estimate the monetary value of the total energy security benefits of this program. The agencies have calculated energy security in very specific terms, as the reduction of both financial and strategic risks caused by potential sudden disruptions in the supply of imported petroleum to the U.S. Reducing the amount of oil imported reduces those risks, and thus increases the nation’s energy security.

The energy security analysis conducted for this rulemaking estimates that the world price of oil will fall modestly in response to lower U.S. demand for refined fuel. One

[oo] See 42 U.S.C section 6201 (2) and Center for Auto Safety v. NHTSA, 739 F. 2d 1322, 1324 (D.C. Cir. 1986).

potential result of this decline in the world price of oil would be an increase in the consumption of petroleum products, particularly outside the U.S. In addition, other fuels could be displaced from the increasing use of oil worldwide. For example, if a decline in the world oil price causes an increase in oil use in China, India, or another country's industrial sector, this increase in oil consumption may displace natural gas usage. Alternatively, the increased oil use could result in a decrease in coal used to produce electricity. An increase in the consumption of petroleum products particularly outside the U.S., could lead to a modest increase in emissions of greenhouse gases, criteria air pollutants, and airborne toxics from their refining and use. However, lower usage of, for example, displaced coal would result in a decrease in greenhouse gas emissions. Therefore, any assessment of the impacts on GHG emissions from a potential increase in world oil demand would need to take into account the impacts on all portions of the global energy sector. The agencies' analyses have not attempted to estimate these effects.

4.2.9 Air pollutant emissions

Car and light truck use, fuel refining, and fuel distribution and retailing also generate emissions of certain criteria air pollutants, including carbon monoxide (CO), hydrocarbon compounds (usually referred to as "volatile organic compounds," or VOC), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2). Due to regulatory structure, emissions of most of these pollutants are associated with the number of vehicle miles driven, rather than with the quantity of fuel consumed. Sulfur dioxide is an exception, as described below.

While reductions in fuel refining and distribution that result from lower fuel consumption will reduce emissions of criteria pollutants, additional vehicle use associated with the rebound effect and additional electricity generation to meet the demand of plug-in electric vehicles will increase emissions of these pollutants. Thus the net effect of stricter fuel efficiency and GHG standards on total emissions of each criteria pollutant depends on the relative magnitudes of reduced emissions during fuel refining and distribution, increases in emissions from additional vehicle use, and changes in electricity generation (increases due to EV/PHEVs and decreases due to reduced gasoline production at refineries). Because the relationship between the emission rates in each sector (emissions per gallon refined of fuel, mile driven, or kwh generated) is different for each criteria pollutant, the net effect of increases in fuel efficiency and GHG standards on total emissions of each pollutant differs.

4.2.9.1 Emissions of criteria air pollutants

EPA and NHTSA calculated the net changes in domestic emissions of each criteria pollutant by summing the increases in its emissions projected to result from increased vehicle use, changes in electricity production, and the reductions in emissions anticipated to result from lower domestic fuel refining and distribution. As indicated previously, the effect of adopting improved fuel efficiency and GHG standards on total emissions of each criteria pollutant depends on the relative magnitudes of the resulting reduction in emissions from fuel refining and distribution, and the increase in emissions from additional vehicle use.

4.2.9.2 Vehicles

For the analysis of criteria emissions in this rule, EPA and NHTSA estimate the increases in emissions of each criteria air pollutant from additional vehicle use by multiplying the increase in total miles driven by cars and light trucks of each model year and age by their estimated emission rates per vehicle-mile of each pollutant. These emission rates differ between cars and light trucks, between gasoline and diesel vehicles, and by age. With the exception of SO_2, the agencies calculated the increase in emissions of these criteria pollutants from added car and light truck use by multiplying the estimated increases in vehicle use during each year over their expected lifetimes by per-mile emission rates appropriate to each vehicle type, fuel used, model year, and age as of that future year.

As in the MY 2012-2016 rulemaking and the proposal, the relevant emission rates were estimated by U.S. EPA using the most recent version of the Motor Vehicle Emission Simulator (MOVES2010a).[49] The downstream emission rates are unchanged from the proposal, and no comments were received on the use of the MOVES model or its configuration. The MOVES model assumes that the per-mile rates at which these pollutants are emitted are determined by EPA regulations and the effectiveness of after-treatment of engine exhaust emissions, and are thus unaffected by changes in car and light truck fuel economy. The MOVES modeling conducted for this rule is assuming RFS2 volumes of renewable fuel volumes in both the "reference case" and the control case.[pp] The emission analysis assumed a 10% ethanol fuel supply.[qq]As a consequence, the downstream impacts of required increases in fuel economy on emissions of these pollutants from car and light truck use are determined entirely by the increases in driving that result from the fuel economy rebound effect.

Emission factors in the MOVES database are expressed in the form of grams per vehicle-hour of operation. To convert these emission factors to grams per mile, MOVES was run for the year 2050, and was programmed to report aggregate emissions from vehicle start, running, brake and tirewear and crankcase exhaust operations. EPA analysts selected the year 2050 in order to generate emission factors that were representative of lifetime average emission rates for vehicles meeting the agency's Tier 2 emission standard.[rr] Separate estimates were developed for each vehicle type and model year, as well as for each state and month, in order to reflect the effects of regional and temporal variation in temperature and other relevant variables on emissions.

The MOVES emissions estimates were then summed to the model year level and divided by total distance traveled by vehicles of that model year in order to produce per-mile

[pp] The agencies assume 100 percent E10 in both the reference and control cases, which is a simplifying assumption that is appropriate to the level of detail necessary for our rulemaking analyses.
[qq] More discussion on fuel supply and this rule is in Preamble Section III.F
[rr] Because all light-duty emission rates in MOVES2010a are assumed to be invariant after MY 2010, a calendar-year 2050 run produced a full set of emission rates that reflect anticipated deterioration in the effectiveness of vehicles' emission control systems with increasing age and accumulated mileage for post-MY 2010 vehicles.

emission factors for each pollutant. The resulting emission rates represent average values across the nation, and incorporate typical variation in temperature and other operating conditions affecting emissions over an entire calendar year. These national average rates also reflect county-specific differences in fuel composition, as well as in the presence and type of vehicle inspection and maintenance programs.[ss]

Emission rates for the criteria pollutant SO_2 were calculated by using average fuel sulfur content estimates supplied by EPA, together with the simplifying assumption that the entire sulfur content of fuel is emitted in the form of SO_2. These calculations assumed that national average gasoline and diesel sulfur levels would remain at current levels, because there are no current regulations which will change those levels, and we have no expectation that the market will cause such changes on its own.[tt] Therefore, unlike many other criteria pollutants, sulfur dioxide emissions from vehicle use decline in proportion to the decrease in fuel consumption.

4.2.9.3 Fuel Production and Transport

Emissions of criteria air pollutants also occur during each phase of fuel production and distribution, including crude oil extraction and transportation, fuel refining, and fuel storage and transportation. The reduction in emissions during each of these phases depends on the extent to which fuel savings result in lower imports of refined fuel, or in reduced domestic fuel refining. To a lesser extent, they also depend on whether reductions in domestic gasoline refining are reflected in reduced imports of crude oil or in reduced domestic extraction of petroleum.

Both EPA's and NHTSA's analyses assume that reductions in imports of refined fuel would reduce criteria pollutant emissions during fuel storage and distribution only. Reductions in domestic fuel refining using imported crude oil as a feedstock are assumed to reduce emissions during fuel refining, storage, and distribution, because each of these activities would be reduced. Finally, reduced domestic fuel refining using domestically-produced crude oil is assumed to reduce emissions during all phases of fuel production and distribution.[uu] This includes reducing emissions from electric generating units that power the refineries.

[ss] The national mix of fuel types includes county-level market shares of conventional and reformulated gasoline, as well as county-level variation in sulfur content, ethanol fractions, and other fuel properties. Inspection/maintenance programs at the county level account for detailed program design elements such as test type, inspection frequency, and program coverage by vehicle type and age.
[tt] These are 30 and 15 parts per million (ppm, measured on a mass basis) for gasoline and diesel respectively, which produces emission rates of 0.17 grams of SO_2 per gallon of gasoline and 0.10 grams per gallon of diesel.
[uu] In effect, this assumes that the distances crude oil travels to U.S. refineries are approximately the same regardless of whether it travels from domestic oilfields or import terminals, and that the distances that gasoline travels from refineries to retail stations are approximately the same as those from import terminals to gasoline stations.

The agencies estimated the reductions in criteria pollutant emissions from producing and distributing fuel that would occur under alternative fuel efficiency and GHG standards using emission rates obtained from Argonne National Laboratories' Greenhouse Gases and Regulated Emissions in Transportation (GREET) model.[50,vv] The GREET model provides separate estimates of air pollutant emissions that occur in four phases of fuel production and distribution: crude oil extraction, crude oil transportation and storage, fuel refining, and fuel distribution and storage.[ww] EPA modified this version of the GREET model to change certain assumptions about emissions during crude petroleum extraction and transportation, as well as to update its emission rates to reflect adopted and pending EPA emission standards. [51] EPA also incorporated emission factors for the air toxics estimated in this analysis: benzene, 1,3-butadiene, acetaldehyde, acrolein, and formaldehyde. [52]

The agency converted these emission rates from the mass per fuel energy content basis on which GREET reports them to mass per gallon of fuel supplied using the estimates of fuel energy content reported by GREET. The resulting emission rates were applied to both EPA's and NHTSA's estimates of fuel consumption under alternative fuel efficiency standards to develop estimates of total emissions of each criteria pollutant during fuel production and distribution. The assumptions about the effects of *changes* in fuel consumption on domestic and imported sources of fuel supply discussed above were then employed to calculate the effects of reductions in fuel use from alternative fuel efficiency and GHG standards on changes in domestic emissions of each criteria pollutant throughout the fuel supply and distribution process. Additional discussion of the emission factors related to fuel production and transport is provided in EPA's RIA.

Electricity Generation

For the NPRM, EPA and NHTSA utilized emission factors from EPA's Integrated Planning Model (IPM) to assess the increased electricity used for EVs and PHEVs. As discussed in our respective RIAs, EPA and NHTSA have independently developed updated emission factors for use in estimating these emissions. Comments on estimation of these emissions are also discussed in sections III and IV of the preamble, and in the agencies' RIAs.

4.2.9.4 Estimated values of reducing PM-related emissions in the model year analysis

The agencies' analysis of $PM_{2.5}$-related benefits over the lifetime of specific model years uses a "benefit-per-ton" method to estimate selected $PM_{2.5}$-related health benefits.

[vv] GREET has been updated since the last major update of the EPA impact spreadsheet, most recently with GREET 1 2012, released on June 28, 2012. Due to the lead time required for modeling, and the resultant timing constraints, these updates have not been incorporated in this analysis. The agencies will monitor relevant developments for future rulemakings.

[ww] Emissions that occur during vehicle refueling at retail gasoline stations (primarily evaporative emissions of volatile organic compounds, or VOCs) are already accounted for in the "tailpipe" emission factors used to estimate the emissions generated by increased light truck use. GREET estimates emissions in each phase of gasoline production and distribution in mass per unit of gasoline energy content; these factors are then converted to mass per gallon of gasoline using the average energy content of gasoline.

These $PM_{2.5}$-related benefit-per-ton estimates provide the total monetized human health benefits (the sum of premature mortality and premature morbidity) of reducing one ton of directly emitted $PM_{2.5}$, or one ton of a pollutant that contributes to secondarily-formed $PM_{2.5}$ (such as NOx and SOx) from a specified source. Ideally, the human health benefits would be estimated based on changes in ambient $PM_{2.5}$ concentrations and population exposure, as determined by complete air quality and exposure modeling. However, conducting such detailed modeling for the model year analysis was not possible within the timeframe for the final rule. Note that EPA and NHTSA conducted full-scale photochemical air quality modeling for the calendar year analysis in 2030. Please refer to Chapter 6.2 of the RIA for a description of EPA's air quality modeling results and to Chapter 6.3 for a description of the quantified and monetized PM- and ozone-related health impacts of the FRM.

Due to analytical limitations, the estimated benefit-per-ton values do not include comparable benefits related to reductions in other ambient concentrations of criteria pollutants (such as ozone, NO_2 or SO_2) or toxic air pollutants, nor do they monetize all of the potential health and welfare effects associated with $PM_{2.5}$ or the other criteria pollutants. As a result, monetizing PM-related health impacts alone underestimates the benefits associated with reductions of the suite of non-GHG pollutants that would be reduced by the final standards.

The dollar-per-ton estimates used to monetize reductions in emissions that contribute to ambient concentrations of $PM_{2.5}$ are provided in Table 4-11.

Table 4-11 $PM_{2.5}$-related Benefits-per-ton Values (2010$)[a]

Year	All Sources[d]	Upstream (Non-EGU) Sources[d]		Mobile Sources	
	SO_2	NO_X	Direct $PM_{2.5}$	NO_X	Direct $PM_{2.5}$
Dollar-per-ton Derived from American Cancer Society Analysis (Pope et al., 2002) Using a 3 Percent Discount Rate[c]					
2015	$30,000	$4,900	$230,000	$5,100	$280,000
2020	$33,000	$5,400	$250,000	$5,600	$310,000
2030	$38,000	$6,400	$290,000	$6,700	$370,000
2040	$45,000	$7,600	$340,000	$8,000	$440,000
Dollar-per-ton Derived from American Cancer Society Analysis (Pope et al., 2002) Estimated Using a 7 Percent Discount Rate[c]					
2015	$27,000	$4,500	$210,000	$4,600	$250,000
2020	$30,000	$4,900	$230,000	$5,100	$280,000
2030	$35,000	$5,800	$270,000	$6,100	$330,000
2040	$41,000	$6,900	$310,000	$7,300	$400,000
Dollar-per-ton Derived from Six Cities Analysis (Laden et al., 2006) Estimated Using a 3 Percent Discount Rate[c]					
2015	$73,000	$12,000	$560,000	$12,000	$680,000
2020	$80,000	$13,000	$620,000	$14,000	$750,000
2030	$94,000	$16,000	$720,000	$16,000	$900,000
2040	$110,000	$19,000	$840,000	$20,000	$1,100,000
Dollar-per-ton Derived from Six Cities Analysis (Laden et al., 2006) Estimated Using a 7 Percent Discount Rate[c]					
2015	$66,000	$11,000	$510,000	$11,000	$620,000
2020	$72,000	$12,000	$560,000	$12,000	$680,000
2030	$84,000	$14,000	$650,000	$15,000	$810,000
2040	$99,000	$17,000	$760,000	$18,000	$960,000

[a] Total dollar-per-ton estimates include monetized $PM_{2.5}$-related premature mortality and morbidity endpoints. Range of estimates are a function of the estimate of $PM_{2.5}$-related premature mortality derived from either the ACS study (Pope et al., 2002) or the Six-Cities study (Laden et al., 2006).
[b] Dollar-per-ton values were estimated for the years 2015, 2020, and 2030. For 2040, EPA extrapolated exponentially based on the growth between 2020 and 2030.
[c] The dollar-per-ton estimates presented in this table assume either a 3 percent or 7 percent discount rate in the valuation of premature mortality to account for a twenty-year segmented cessation lag.
[d] Note that the dollar-per-ton value for SO2 is based on the value for Stationary (Non-EGU) sources; no SO2 value was estimated for mobile sources.

As Table 4-11 indicates, EPA projects that the per-ton values for reducing emissions of criteria pollutants from both vehicle use and stationary sources such as fuel refineries and storage facilities will increase over time.[xx] These projected increases reflect rising income levels, which are assumed to increase affected individuals' willingness to pay for reduced exposure to health threats from air pollution. They also reflect future population growth and increased life expectancy, which expands the size of the population exposed to air pollution in both urban and rural areas, especially in older age groups with the highest mortality risk.[53,yy]

For certain $PM_{2.5}$-related pollutants (such as direct $PM_{2.5}$ and NOx), EPA estimates different per-ton values for reducing mobile source emissions than for reductions in emissions of the same pollutant from stationary sources such as fuel refineries and storage facilities. These reflect differences in the typical geographic distributions of emissions of each pollutant by different sources, their contributions to ambient levels of $PM_{2.5}$, and resulting changes in population exposure. EPA and NHTSA apply these separate values to its estimates of changes in emissions from vehicle use and from fuel production and distribution to determine the net change in total economic damages from emissions of those pollutants.

The benefit per-ton technique has been used in previous analyses, including the 2012-2016 Light-Duty Greenhouse Gas Rule,[54] the Ozone National Ambient Air Quality Standards (NAAQS) RIA,[55] the Portland Cement National Emissions Standards for Hazardous Air Pollutants (NESHAP) RIA,[56] and the final NO_2 NAAQS.[57] Table 4-12 shows the quantified and monetized $PM_{2.5}$-related co-benefits that are captured in these benefit-per-ton estimates, and also lists other effects that remain un-quantified and are thus excluded from the estimates.

Table 4-12 Human Health and Welfare Effects of $PM_{2.5}$

Pollutant / Effect	Quantified and Monetized in Primary Estimates	Un-quantified Effects Changes in:
$PM_{2.5}$	Adult premature mortality Bronchitis: chronic and acute Hospital admissions: respiratory and	Subchronic bronchitis cases Low birth weight Pulmonary function

[xx] As we discuss in the emissions chapter of EPA's RIA (Chapter 4), the rule would yield emission reductions from upstream refining and fuel distribution due to decreased petroleum consumption.
[yy] For more information about EPA's population projections, please refer to the following: http://www.epa.gov/air/benmap/models/BenMAPManualAppendicesAugust2010.pdf (See Appendix K)

Pollutant / Effect	Quantified and Monetized in Primary Estimates	Un-quantified Effects Changes in:
	cardiovascular Emergency room visits for asthma Nonfatal heart attacks (myocardial infarction) Lower and upper respiratory illness Minor restricted-activity days Work loss days Asthma exacerbations (asthmatic population) Infant mortality	Chronic respiratory diseases other than chronic bronchitis Non-asthma respiratory emergency room visits Visibility Household soiling

Consistent with the NO_2 NAAQS,[zz] the benefits estimates utilize concentration-response functions as reported in the epidemiology literature. Readers interested in reviewing the complete methodology for creating the benefit-per-ton estimates used in this analysis can consult the Technical Support Document (TSD)[58] accompanying the final ozone NAAQS RIA. Readers can also refer to Fann et al. (2009)[59] for a detailed description of the benefit-per-ton methodology.[aaa]

As described above, national per-ton estimates were developed for selected pollutant/source category combinations. The per-ton values calculated therefore apply only to tons reduced from those specific pollutant/source combinations (*e.g.*, NO_2 emitted from mobile sources; direct PM emitted from stationary sources). Our estimate of total $PM_{2.5}$ benefits is therefore based on the total direct $PM_{2.5}$ and $PM_{2.5}$–related precursor emissions (NOx, SOx, and VOCs) controlled from each source and multiplied by the respective per-ton values of reducing emissions from that source.

Reductions in PM-related mortality provide the majority of the monetized value in each benefit-per-ton estimate. Typically, the premature mortality-related effect coefficients that underlie the benefits-per-ton estimates are drawn from epidemiology studies that examine two large population cohorts: the American Cancer Society cohort (Pope et al., 2002)[60] and the Harvard Six Cities cohort (Laden et al., 2006).[61] The concentration-response (C-R) function developed from the extended analysis of American Cancer Society (ACS) cohort, as

[zz] Although we summarize the main issues in this chapter, we encourage interested readers to see benefits chapter of the NO2 NAAQS for a more detailed description of recent changes to the PM benefits presentation and preference for the no-threshold model.

[aaa] The values included in this report are different from those presented in the article cited above. Benefits methods change to reflect new information and evaluation of the science. Since publication of the June 2009 article, EPA has made two significant changes to its benefits methods: (1) We no longer assume that a threshold exists in PM-related models of health impacts, which is consistent with the findings reported in published research; and (2) We have revised the Value of a Statistical Life to equal $6.3 million (year 2000$), up from an estimate of $5.5 million (year 2000$) used in the June 2009 report. Please refer to the following website for updates to the dollar-per-ton estimates: http://www.epa.gov/air/benmap/bpt.html

reported in Pope et al. (2002), has previously been used by EPA to generate its primary benefits estimate. The extended analysis of the Harvard Six Cities cohort, as reported by Laden et al (2006), was published after the completion of the Staff Paper for the 2006 $PM_{2.5}$ NAAQS and has been used as an alternative estimate in the $PM_{2.5}$ NAAQS RIA and $PM_{2.5}$ co-benefits estimates in analyses completed since the $PM_{2.5}$ NAAQS.

These studies provide logical choices for co-equal anchor points when presenting PM-related benefits because, while both studies are well designed and peer-reviewed, there are strengths and weaknesses inherent in each. Although EPA's primary method of characterizing PM-related premature mortality is to use both studies to generate a co-equal range of benefits estimates, EPA has chosen to present only the benefit-per-ton value derived from the ACS study in its summary tables of total Model Year costs and benefits (See Preamble Section III.H.10 and RIA Chapter 7). This decision was made to provide the reader with summary tables that are easier to understand and interpret and does not convey any preference for one study over the other. We note that this is also the more conservative of the two estimates - PM-related benefits would be approximately 245 percent (or nearly two-and-a-half times) larger had we used the per-ton benefit values based on the Harvard Six Cities study instead.

As is the nature of benefits analyses, assumptions and methods evolve over time to reflect the most current interpretation of the scientific and economic literature. For a period of time (2004-2008), EPA's Office of Air and Radiation (OAR) valued mortality risk reductions using a value of statistical life (VSL) estimate derived from a limited analysis of some of the available studies. OAR arrived at a VSL using a range of $1 million to $10 million (2000$) consistent with two meta-analyses of the wage-risk literature.

The $1 million value represented the lower end of the interquartile range from the Mrozek and Taylor (2002)[62] meta-analysis of 33 studies. The $10 million value represented the upper end of the interquartile range from the Viscusi and Aldy (2003)[63] meta-analysis of 43 studies. The mean estimate of $5.5 million (2000$) was also consistent with the mean VSL of $5.4 million estimated in the Kochi et al. (2006)[64] meta-analysis. However, the Agency neither changed its official guidance on the use of VSL in rulemakings nor subjected the interim estimate to a scientific peer-review process through the Science Advisory Board (SAB) or other peer-review group.

Until updated guidance is available, EPA determined that a single, peer-reviewed estimate applied consistently best reflects the Science Advisory Board Environmental Economics Advisory Committee (SAB-EEAC) advice it has received. Therefore, EPA has decided to apply the VSL that was vetted and endorsed by the SAB in the Guidelines for Preparing Economic Analyses (U.S. EPA, 2000)[65] while they continue efforts to update their guidance on this issue.[bbb] This approach calculates a mean value across VSL estimates

[bbb] In the update of the Economic Guidelines (U.S. EPA, 2011), EPA retained the VSL endorsed by the SAB with the understanding that further updates to the mortality risk valuation guidance would be forthcoming in the

derived from 26 labor market and contingent valuation studies published between 1974 and 1991. The mean VSL across these studies is \$6.3 million (2000\$). The dollar-per-ton estimates used in this analysis are based on this revised VSL.[ccc]

The benefit-per-ton estimates are subject to a number of assumptions and uncertainties.

- They do not reflect local variability in population density, meteorology, exposure, baseline health incidence rates, or other local factors that might lead to an overestimate or underestimate of the actual benefits of controlling fine particulates in specific locations. Please refer to Chapter 6 of EPA's RIA for the description of the agency's quantification and monetization of PM- and ozone-related health impacts for the final standards.
- This analysis assumes that all fine particles, regardless of their chemical composition, are equally potent in causing premature mortality. This is an important assumption, because $PM_{2.5}$ produced via transported precursors emitted from stationary sources may differ significantly from direct $PM_{2.5}$ released from engines and other industrial sources. At the present time, however, no clear scientific grounds exist for supporting differential effects estimates by particle type.
- This analysis assumes that the health impact function for fine particles is linear within the range of ambient concentrations under consideration. Thus, the estimates include health benefits from reducing fine particles in areas with varied initial concentrations of $PM_{2.5,}$ including both regions that are in attainment with fine particle standard and those that do not meet the standard, down to the lowest modeled concentrations.
- There are several health benefits categories that EPA and NHTSA were unable to quantify due to limitations associated with using benefits-per-ton estimates, several of which could be substantial. Because NO_X and VOC emissions are also precursors to ozone, changes in NO_X and VOC would also impact ozone formation and the health effects associated with ozone exposure. Benefits-per-ton estimates for ozone do not exist due to issues associated with the complexity of the atmospheric air chemistry and nonlinearities associated with ozone formation. The PM-related benefits-per-ton estimates also do not include any human welfare or ecological benefits. Please refer to Chapter 6.3 of EPA's RIA for a description of the unquantified co-pollutant benefits associated with this rulemaking.

As mentioned above, emissions changes and benefits-per-ton estimates alone are not a good indication of local or regional air quality and health impacts, as the localized impacts associated with the rulemaking may vary significantly. Additionally, the atmospheric

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near future. The update of the Economic Guidelines is available on the Internet at http://yosemite.epa.gov/ee/epa/eed.nsf/pages/Guidelines.html/$file/Guidelines.pdf.

[ccc] This value differs from the Department of Transportation's most recent estimate of the value of preventing transportation-related fatalities, which is \$6.1 million when expressed in today's (2011) dollars.

chemistry related to ambient concentrations of $PM_{2.5}$, ozone and air toxics is very complex. Full-scale photochemical modeling is therefore necessary to provide the needed spatial and temporal detail to more completely and accurately estimate the changes in ambient levels of these pollutants and their associated health and welfare impacts. For this final rule, EPA and NHTSA conducted national-scale air quality modeling analyses for 2030 to analyze the impacts of the standards on $PM_{2.5}$, ozone, and selected air toxics.

4.2.10 Reductions in emissions of greenhouse gases

Emissions of carbon dioxide and other greenhouse gases (GHGs) occur throughout the process of producing and distributing transportation fuels, as well as from fuel combustion itself. By increasing fuel efficiency and thus reducing the volume of fuel consumed by passenger cars and light trucks, the standards will reduce GHG emissions generated by fuel use, as well as throughout the fuel supply cycle. Lowering these emissions is likely to slow the projected pace and reduce the ultimate extent of future changes in the global climate, thus reducing future economic damages that changes in the global climate are otherwise expected to cause. Further, by reducing the probability that climate changes with potentially catastrophic economic or environmental impacts will occur, lowering GHG emissions may also result in economic benefits that exceed the resulting reduction in the expected future economic costs caused by gradual changes in the earth's climatic systems. Quantifying and monetizing benefits from reducing GHG emissions is thus an important step in estimating the total economic benefits likely to result from establishing improved fuel efficiency and GHG standards.

4.2.10.1 Estimating reductions in GHG emissions

NHTSA estimates emissions of carbon dioxide (CO_2) from passenger car and light truck use by multiplying the number of gallons of each type of fuel (gasoline and diesel) they are projected to consume with each alternative CAFE standard in effect by the quantity or mass of CO_2 emissions released per gallon of fuel consumed. EPA directly calculates CO_2 emissions from the projected CO_2 emissions of each vehicle under the CO_2 standards. This calculation assumes that the entire carbon content of each fuel is ultimately converted to CO_2 emissions during the combustion process. The weighted average CO_2 content of certification gasoline is estimated to be 8,887 grams per gallon, while that of diesel fuel is estimated to be approximately 10,200 grams per gallon. For details, please see EPA's and NHTSA's respective RIAs. These same methods were used in the proposal and no comments were received.

Although carbon dioxide emissions account for nearly 95 percent of total GHG emissions that result from fuel combustion during vehicle use, emissions of other GHGs are potentially significant as well because of their higher "potency" as GHGs than that of CO_2 itself. EPA and NHTSA estimated the increases in emissions of methane (CH_4) and nitrous oxide (N_2O) from additional vehicle use by multiplying the increase in total miles driven by cars and light trucks of each model year and age by emission rates per vehicle-mile for these GHGs. These emission rates, which differ between cars and light trucks as well as between gasoline and diesel vehicles, were estimated by EPA using MOVES 2010a.

The MOVES model assumes that the per-mile rates at which cars and light trucks emit these non-CO_2 GHGs are determined by the efficiency of fuel combustion during engine operation and chemical reactions that occur during catalytic after-treatment of engine exhaust, and are thus independent of vehicles' fuel consumption rates. Thus MOVES emission factors for these GHGs, which are expressed per mile of vehicle travel, are assumed to be unaffected by changes in fuel economy.

Much like criteria pollutants, emissions of GHGs occur during each phase of fuel production and distribution, including crude oil extraction and transportation, fuel refining, and fuel storage and transportation. Emissions of GHGs also occur in generating electricity, which the agencies' analysis anticipates will account for an increased but likely still small share of energy consumption in the model years subject to the standards. The agencies' analyses assume that reductions in fuel consumption would reduce global GHG emissions during all four phases of fuel production and distribution.[ddd] Unlike criteria pollutants, the agencies report both domestic and international reductions in GHG emissions. EPA derived GHG emission rates corresponding to producing and distributing fuel from Argonne National Laboratories' Greenhouse Gases and Regulated Emissions in Transportation (GREET) model.[66][eee]

For the NPRM, EPA and NHTSA utilized emission factors from EPA's Integrated Planning Model (IPM) to assess the increased electricity used for EVs and PHEVs. As discussed in our respective RIAs, EPA and NHTSA have independently developed updated emission factors for use in estimating these emissions. Comments on estimation of these emissions are also discussed in sections III and IV of the preamble, and in the agencies' RIAs.

Increases in emissions of non-CO_2 GHGs are converted to equivalent increases in CO_2 emissions using estimates of the Global Warming Potential (GWP) of methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons (HFC-134a).[fff] These GWPs are one way of accounting

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[ddd] The four stages are crude oil extraction, crude oil transportation and storage, fuel refining, and fuel distribution and storage

[eee] This version of the model was modified, and is discussed in section 4.2.9.1

[fff] As in the MY 2012-2016 LD rules and in the MY 2014-2018 MD and HD rules, the global warming potentials (GWP) used in this rulemaking are consistent with the 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 100-year GWP values from the 1995 IPCC Second Assessment Report (SAR) are used in the official U.S. GHG inventory submission to the United Nations Framework Convention on Climate Change (UNFCCC) per the reporting requirements under that international convention. The UNFCCC recently agreed on revisions to the national GHG inventory reporting requirements, and will begin using the 100-year GWP values from AR4 for inventory submissions in the future (United Nations Framework Convention on Climate Change, "Decisions adopted by the Conference of the Parties: 15/CP.17 'Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention'," FCCC/CP/2011/9/Add.2, Durban, South Africa, December 2011). According to the AR4, N_2O has a 100-year GWP of 298, CH4 has a 100-year GWP of 25, and HFC-134a has a 100-year GWP of 1430.

for the higher radiative forcing capacity and differing lifetimes of methane and nitrous oxide when they are released into the earth's atmosphere, measured relative to that of CO_2 itself. Because these gases differ in atmospheric lifetimes, their relative damages are not constant over time. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Methane contributes to health and ecosystem effects arising from increases in tropospheric ozone, while damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Noting these caveats, the CO_2 equivalents of increases in emissions of these gases are then added to the increases in emissions of CO_2 itself to summarize the effect of the total increase in CO_2-equivalent GHG emissions from vehicle use.

4.2.10.2 Economic benefits from reducing GHG emissions

NHTSA and EPA have taken the economic benefits of reducing CO_2 emissions (or avoiding damages from increased emissions) into account in developing the final GHG and CAFE standards and in assessing the economic benefits of the final standards. Specifically, NHTSA and EPA have assigned dollar values to reductions in carbon dioxide (CO_2) emissions using estimates of the global "social cost of carbon" (SCC). The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change. The SCC is expressed in constant dollars per additional metric ton of CO_2 emissions occurring during a specific year, and is higher for more distant future years because the damages caused by an additional ton of emissions increase with larger concentrations of CO_2 in the earth's atmosphere.

The estimates used in this analysis were developed through an interagency process that included EPA, DOT/NHTSA, and other executive branch entities, and concluded in February 2010. The interagency group focused on global SCC values because emissions of CO_2 involve a global externality: greenhouse gases contribute to damages around the world wherever they are emitted. Consequently, to address the global nature of the climate change problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Furthermore, climate change occurs over very long time horizons and represents a problem that the United States cannot solve independently. The February 2010 SCC Technical Support Document (SCC TSD) provides a complete discussion of the SCC estimates and the methods used to develop them.[67]

We first used these SCC estimates in the benefits analysis for the final joint EPA/DOT Rulemaking to establish 2012-2016 Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; see the rule's preamble for discussion about application of the SCC (75 FR 25324; May 7, 2010). We have continued to use these estimates in other rulemaking analyses, including the Greenhouse Gas Emission Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles (76 FR 57106; 9/15/11). Finally, see also preamble Section III.H.6, Section IV.C.3.l, EPA RIA Chapter 7.1, and NHTSA RIA VIII.C for discussion about the application of SCC estimates to this final rule.

The SCC estimates corresponding to assumed values of the discount rate are shown below in Table 4-13.

Table 4-13 Social Cost of of CO_2, 2017 – 2050[a] (in 2010 dollars)

Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th percentile
2017	$6	$26	$41	$79
2020	$7	$27	$43	$84
2025	$9	$31	$48	$94
2030	$10	$34	$52	$104
2035	$12	$37	$56	$114
2040	$13	$41	$61	$124
2045	$15	$44	$64	$133
2050	$16	$47	$68	$142

[a] The SCC values apply to emissions occurring during each year shown (in 2010 dollars), and represent the present value of future damages as of the year shown.

As Table 4-13 shows, the SCC estimates selected by the interagency group for use in regulatory analyses range from roughly $6 to about $79 (in 2010 dollars) for emissions occurring in the year 2017. The first three estimates are based on the average SCC estimated using different models and reflect discount rates of 5, 3, and 2.5 percent, respectively. The fourth value is included to represent the possibility of higher-than-expected impacts from accumulation of GHGs in the earth's atmosphere, and the consequently larger economic damages. For this purpose, the interagency group elected to use the SCC value for the 95th percentile at a 3 percent discount rate.

The value that the interagency group centered its attention on is the average SCC estimate at a 3 percent discount rate, or about $26 per metric ton in 2017. To capture the uncertainties involved in regulatory impact analysis, however, the group emphasized the importance of considering the full range of estimated SCC values. As the table shows, the SCC estimates rise over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change; for example, the average SCC at 3 percent increases from about $26 per ton of CO_2 in 2017 to approximately $34 per ton of CO_2 by 2030.

Reductions in CO_2 emissions that are projected to result from lower fuel consumption, refining, and distribution during each future year are multiplied by the appropriate SCC estimates for that year, to determine the range of total economic benefits from reduced emissions during that year. For internal consistency, these annual benefits are discounted back to net present value terms using a discount rate that is consistent with that used to develop each SCC estimate.

This final rulemaking also responds to comments regarding the valuation of non-CO_2 GHGs and analyzes changes in non-CO_2 GHGs. The 2010 interagency group, however, did not directly estimate the social cost of non-CO_2 GHGs. One way to approximate the value of marginal non-CO_2 GHG emission reductions in the absence of direct model estimates is to convert the reductions to CO_2-equivalents which may then be valued using the SCC. Conversion to CO_2-e is typically done using the global warming potential (GWP) for the non-CO_2 gas.[ggg] We refer to this as the "GWP approach."

One potential problem with using temporally aggregated statistics such as GWP is that the additional radiative forcing from the GHG perturbation is not constant over time and any differences in temporal dynamics between gases will be lost. This is a potentially confounding issue given that the social cost of GHGs is based on a discounted stream of damages that are non-linear in temperature. For example, methane has an expected adjusted atmospheric lifetime of about 12 years and associated GWP of 25 (IPCC Fourth Assessment Report (AR4) 100-year GWP estimate). Gases with a relatively shorter lifetime, such as methane, have impacts that occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases such as CO_2, while the GWP treats additional forcing the same independent of when it occurs in time. Furthermore, the baseline temperature change is lower in the near term and therefore the additional warming from relatively short lived gases will have a lower marginal impact relative to longer lived gases that have an impact further out in the future when baseline warming is higher. In addition, impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane will result in CO_2 passive fertilization to plants.

In short, the GWP-weighted approach will produce social cost estimates that are less accurate than the directly modeled estimates. A limited number of studies in the published literature explore these differences. A recent working paper (Marten and Newbold, 2011), found that the GWP-weighted benefit estimates for CH_4 and N_2O are likely to be lower than those that would be derived using a directly modeled social cost of the non-CO_2 GHGs for a variety of reasons.[68] [hhh] The GWP reflects only the integrated radiative forcing of a gas over 100 years. In contrast, the directly modeled social cost differs from the GWP because the differences in timing of the warming between gases are explicitly modeled, the non-linear

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[ggg] The GWP is an aggregate measure that approximates the additional energy trapped in the atmosphere over a given timeframe from a perturbation of a non-CO_2 gas relative to CO_2.

[hhh] As discussed in Marten and Newbold, the discount rate influences the relative social cost of a gas, i.e., the ratio of the social cost of the gas and the social cost of CO_2. Methane is a short-lived gas and therefore at higher discount rates, the relative social cost is higher than at low discount rates. Depending on the discount rate, the relative social cost of methane ranged from 22 to 41 in 2015, compared to 25 for the AR4 GWP. The relative social cost of N2O was calculated to be at least 372, much higher than the AR4 value of 298.

effects of temperature change on economic damages are included, and rather than treating all impacts over a hundred years equally, the modeled social cost applies a discount rate but calculates impacts through the year 2300.

The agencies recognize the importance of considering the economic impacts from changes to non-CO_2 GHGs under this final rule. Therefore, in the absence of direct model estimates from the interagency analysis, EPA and NHTSA have used the GWP approach to estimate the dollar value of this rule's non-CO_2 GHG benefits in a sensitivity analysis; these estimates are presented for illustrative purposes and therefore not included in the total benefits estimate for the rulemaking. NHTSA and EPA converted CH_4 and N_2O emissions to CO_2 equivalents using the GWP of each gas, then multiplied these CO_2-equivalent emission by the interagency social cost of CO_2 estimates. EPA also converted HFC-134a emissions to CO_2 equivalents and applied the social cost of carbon.[iii] Please see NHTSA's preamble IV.G.4 and RIA Chapter X and EPA's preamble Section III.H.6 and RIA Chapter 7 for more details about the agencies' respective sensitivity analyses and results.

4.2.11 Benefits due to reduced refueling time

Direct estimates of the value of extended vehicle range are not available in the literature, so the agencies instead calculate the reduction in the required annual number of refueling cycles due to improved fuel economy, and assess the economic value of the resulting benefits. Chief among these benefits is the time that owners save by spending less time both in search of fueling stations and in the act of pumping and paying for fuel.

NHTSA conducted an analysis to estimate the benefits associated with reduced refueling, which both agencies are using in their respective analyses of overall programmatic costs and benefits, but which the agencies are applying slightly differently. See chapter VIII of NHTSA's RIA and chapter 7 of EPA's RIA for more details.

[iii] As in the MY 2012-2016 LD rules and MY 2014-2018 MD and HD rules, the global warming potentials (GWP) used in this rulemaking are consistent with the 100-year time frame values in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). At this time, the 100-year GWP values from the 1995 IPCC Second Assessment Report (SAR) are used in the official U.S. GHG inventory submission to the United Nations Framework Convention on Climate Change (UNFCCC) per the reporting requirements under that international convention. The UNFCCC recently agreed on revisions to the national GHG inventory reporting requirements, and will begin using the 100-year GWP values from AR4 for inventory submissions in the future (United Nations Framework Convention on Climate Change, "Decisions adopted by the Conference of the Parties: 15/CP.17 'Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention'," FCCC/CP/2011/9/Add.2, Durban, South Africa, December 2011). According to the AR4, N_2O has a 100-year GWP of 298, CH4 has a 100-year GWP of 25, and HFC-134a has a 100-year GWP of 1430.

4.2.12 Discounting future benefits and costs

Discounting future fuel savings and other benefits is intended to account for the reduction in their value to society when they are deferred until some future date, rather than received immediately. The discount rate expresses the percent decline in the value of these benefits – as viewed from the current perspective – for each year they are deferred into the future. In evaluating the benefits from alternative increases in fuel economy and GHG standards for MY 2017-2025 passenger cars and light trucks, EPA and NHTSA consider discount rates of both 3 and 7 percent per year.

Three percent may be the appropriate rate for discounting future benefits from increased fuel economy and GHG standards because most or all of vehicle manufacturers' costs for complying with improved fuel economy and GHG standards are likely to be reflected in higher sales prices for their new vehicle models. By increasing sales prices for new cars and light trucks, GHG and CAFE regulations will thus primarily affect vehicle purchases and other private consumption decisions.

Both economic theory and OMB guidance on discounting indicate that the future benefits and costs of regulations that mainly affect private consumption should be discounted at the consumption rate of time preference.[69] OMB guidance indicates that savers appear to discount future consumption at an average real (that is, adjusted to remove the effect of inflation) rate of about 3 percent when they face little risk about its likely level, which makes it a reasonable estimate of the consumption rate of time preference.[70] Because there is some uncertainty about the extent to which vehicle manufacturers will be able to recover their costs for complying with improved fuel economy and GHG standards by increasing vehicle sales prices, however, the use of a higher percent discount rate may also be appropriate. OMB guidance indicates that the real economy-wide opportunity cost of capital is the appropriate discount rate to apply to future benefits and costs when the primary effect of a regulation is "…to displace or alter the use of capital in the private sector," and estimates that this rate currently averages about 7 percent.[71] Thus the agencies have employed both 3 and 7 percent rates to discount projected future benefits and costs resulting from improved fuel economy and GHG standards for MY 2017-2025 passenger cars and light trucks.

One important exception to these values are the rates used to discount benefits from reducing CO_2 emissions from the years in which reduced emissions occur, which span the lifetimes of model year 2017-2025 cars and light trucks, to their present values. In order to ensure consistency in the derivation and use of the SCC estimates of the unit values of reducing CO_2 emissions, the total benefits from reducing those emissions during each future year are discounted using the same rates that were used to derive the alternative values of reducing each ton of CO_2 emissions (2.5, 3.0, and 5.0 percent).

4.2.13 Additional Costs of Vehicle Ownership

<u>Sales Taxes:</u>

Consumers may consider the sales taxes they have to pay at the time of purchasing the vehicle. As these costs are transfer payments, they are not included in the societal cost of the program, but they are included as one of the increased costs to the consumer for these standards, when we calculate costs that the consumer pays out for vehicle ownership. The agencies took the most recent auto sales taxes by state[jjj] and weighted them by population by state to determine a national weighted-average sales tax of 5.46 percent. The agencies sought to weight sales taxes by new vehicle sales by state; however, such data were unavailable. It is recognized that for this purpose, new vehicle sales by state is a superior weighting mechanism to Census population; in effort to approximate new vehicle sales by state, a study of the change in new vehicle registrations (using R.L. Polk data) by state across recent years was conducted, resulting in a corresponding set of weights. Use of the weights derived from the study of vehicle registration data resulted in a national weighted-average sales tax rate almost identical to that resulting from the use of Census population estimates as weights, just slightly above 5.5 percent. The agencies opted to utilize Census population rather than the registration-based proxy of new vehicle sales as the basis for computing this weighted average, as the end results were negligibly different and the analytical approach involving new vehicle registrations had not been as thoroughly reviewed.

Financing Costs:

The agencies considered that 70 percent of new vehicle purchasers take out loans to finance their purchases.[kkk] As these costs are transfer payments, they are not included in the societal cost of the program, but they are included as one of the increased costs to the consumer for these standards. Using proprietary forecasts available from Global Insight, estimates of 48-month[lll] bank and auto finance company loan rates for years 2017 through 2025 were developed, which – when deflated by Global Insight's corresponding forecasts of the CPI – range from 3.73% to 5.38%, averaging 5.16 percent over the nine years.[mmm] In the construction of this estimate, it was assumed that there will be an equal distribution of bank and auto finance company loans – an assumption necessitated by the lack of data on the distribution of the volume of loans between the differing types of creditors. The agencies opted to adjust future loan rates using the CPI rather than the GDP deflator, as this analysis is

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[jjj] See http://www.factorywarrantylist.com/car-tax-by-state.html (last accessed April 5, 2012). Note that county, city, and other municipality-specific taxes were excluded from the weighted averages, as the variation in locality taxes within states, lack of accessible documentation of locality rates, and lack of availability of weights to apply to locality taxes complicate the ability to reliably analyze the subject at this level of detail. Localities with relatively high automobile sales taxes may have relatively fewer auto dealerships, as consumers would endeavor to purchase vehicles in areas with lower locality taxes, therefore reducing the impact of the exclusion of municipality-specific taxes from this analysis.

[kkk] Bird, Colin. "Should I Pay Cash, Lease or Finance My New Car?", http://www.cars.com/go/advice/Story.jsp?section=fin&story=should-i-pay-cash&subject=loan-quick-start&referer=advice&aff=sacbee , July 12, 2011, citing CNW Marketing Research. Accessed 9/27/11.

[lll] No projections were available for rates of loan terms of 60 months. The agencies compared the historical difference of 48-month and 60-month loan rates and determined the 48-month rate to be a suitable proxy for the 60-month rate.

[mmm] Global Insight data are available on a fee basis at http://www.ihs.com/products/global-insight/country-analysis/us-economic-forecasts.aspx. Analysis of future auto loan rates is based on Global Insight data available as of March, 2012.

intended to facilitate further analysis from the perspective of the consumer, for which the CPI is the preferred deflation factor.

Insurance Costs:

The agencies considered the rule's impact to consumers' auto insurance expenses over vehicle lifetimes. More expensive vehicles will require more expensive collision and comprehensive (*e.g.*, theft) car insurance. The scope of this analysis is to estimate the increased cost to the consumer for these standards, not the increase in societal costs due to collision and property damage. The increase in insurance costs was estimated from the average value of collision plus comprehensive insurance as a proportion of average new vehicle price. Collision plus comprehensive insurance represent the portion of insurance costs that depend on vehicle value. A recent study by Quality Planning[nnn] provides the average value of collision plus comprehensive insurance for new vehicles, in 2010$, is $521 ($396 of which is collision and $125 of which is comprehensive). The average consumer expenditure for a new passenger car in 2011, according to the Bureau of Economic Analysis was $24,572 and the average price of a new light truck was $31,721 in $2010.[ooo] Using sales volumes from the Bureau, we determined an average passenger car and an average light truck price was $27,953 in $2010 dollars.[ppp]

Dividing the cost to insure a new vehicle by the average price of a new vehicle gives the proportion of comprehensive plus collision insurance as 1.86% of the price of a vehicle. As vehicles' values decline with vehicle age, comprehensive and collision insurance premiums likewise decline. Data on the change in insurance premiums as a function of vehicle age are scarce; however, the agencies utilized data from the aforementioned Quality Planning study that cite the cost to insure the average vehicle on the road today (average age 10.8 years) to enable a linear interpolation of the change in insurance premiums during the first 11 years of a typical vehicle's life.[qqq] To illustrate, as a percentage of the base vehicle price of $27,953, the cost of collision and comprehensive insurance in each of the first five years of a vehicle's life is 1.86%, 1.82%, 1.75%, 1.64%, and 1.50%, respectively, or 8.57% in aggregate. The agencies additionally utilized data from the same Quality Planning study that cite average insurance costs for vehicles greater than 10 years of age (for which the agencies estimated age to be 18, as this is the age at which half of vehicles in service at age 10 remain in service) to extrapolate insurance costs to age 18. Discounting is applied to future insurance

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[nnn] "During Recession, American Drivers Assumed More Risk to Reduce Auto Insurance Costs," Quality Planning, March 2011. See https://www.qualityplanning.com/media/4312/110329%20tough%20times_f2.pdf (last accessed April 4, 2012).

[ooo] U.S. Department of Commerce, Bureau of Economic Analysis, Table 7.2.5S. Auto and Truck Unit Sales, Production, Inventories, Expenditures, and Price, Available at http://www.bea.gov/national/nipaweb/nipa_underlying/Table7.2.5s (last accessed May 4, 2012)

[ppp] http://www.bls.gov/cpi/cpid11av.pdf, Table 1A. Consumer Price Index for All Urban Consumers (CPI-U): U.S. city average, by expenditure category and commodity and service group, for new vehicles.

[qqq]Insurance data did not differentiate between passenger cars and light trucks. Therefore, a 30-year lifetime was assumed in this analysis. Due to several factors, among them discounting, decreased vehicle value with age, and limited vehicle survival in later years of vehicles' lifetimes, this assumption is of minimal impact on the results.

payments in the model's calculations, and all calculations are adjusted by projected vehicle survival rates.

The agencies considered whether to estimate incremental comprehensive and collision insurance premiums only to year 18. As vehicles age, it becomes increasingly impractical to purchase these forms of insurance, and the Quality Planning study indicates that many owners drop these forms of insurance much earlier – in some cases upon repayment of the initial auto loan. The agencies nevertheless use the 30-year lifetime of the vehicle because we use survival-weighted values, which take into account the probability that some vehicles are no longer incurring costs because they no longer exist. This approach may tend to overstate insurance costs, because many owners are not paying insurance premiums even on vehicles that continue to exist. . Therefore, the insurance premiums were age-adjusted to year 30 using the assumption that by end-of-life, no vehicle would remain on comprehensive or collision insurance. This approach provides the agencies with our estimates of the impact of insurance costs on vehicle owners based on the expected increase in MSRP resulting from the rule.

As discussed earlier, the scope of this analysis is to estimate the increased cost to the consumer for these standards, not the increase in societal costs or benefits.

References:

[1]EPA, Final Rulemaking. Motor Vehicle Emissions Federal Test Procedure Revisions 10/1996. 61 FR at 54852

[2] EPA, Fuel Economy Labeling of Motor Vehicles: Revisions To Improve Calculation of Fuel Economy Estimates; Final Rule, 40 CFR Parts 86 and 600, 71 Fed. Reg, 77872 (Dec. 27, 2006). *Available at* http://www.epa.gov/fedrgstr/EPA-AIR/2006/December/Day-27/a9749.pdf.

[3] EPA, *Final Technical Support Document: Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates*, Office of Transportation and Air Quality EPA420-R-06-017 December 2006, Chapter II, http://www.epa.gov/fueleconomy/420r06017.pdf.

[4] See 71 FR at 77887, and U.S. Environmental Protection Agency, Final Technical Support Document, Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates, EPA420-R-06-017, December 2006 for general background on the analysis. See also EPA's Response to Comments (EPA-420-R-11-005) to the 2011 labeling rule, page 189.

[136] EPA and NHTSA, § 600.210-12 Calculation of fuel economy and CO_2 emission values for labeling. Revisions and Additions to Motor Vehicle Fuel Economy Label. Federal Register / Vol. 76, No. 129 / Wednesday,76 Fed. Reg. 39478 (July 6, 2011). § 600.115-11 .

[6] EPA. E15 Waiver Decision, EPA420-F-10-054. October 2010.

[7] EPA, *Final Technical Support Document: Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates*, at 70. Office of Transportation and Air Quality EPA420-R-06-017 December 2006, Chapter II, http://www.epa.gov/fueleconomy/420r06017.pdf.

[8] 75 FRM at 25372

[9] OMB Circular A-4, September 17, 2003. http://www.whitehouse.gov/omb/assets/omb/circulars/a004/a-4.pdf

[10] Lu, S., NHTSA, Regulatory Analysis and Evaluation Division, "Vehicle Survivability and Travel Mileage Schedules," DOT HS 809 952, 8-11 (January 2006). *Available at* http://www-nrd.nhtsa.dot.gov/pdf/nrd-30/NCSA/Rpts/2006/809952.pdf (last accessed Sept. 9, 2011).

[11] FHWA, Highway Statistics, Summary to 1995, Table vm201at http://www.fhwa.dot.gov/ohim/summary95/vm201a.xlw , and annual editions 1996-2005, Table VM-1 at http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm (last accessed Feb. 15, 2010).

[12] Energy Information Adminstration, AEO 2011 Final Relase, Light Duty Vehicle Miles Traveled by Technology Type. http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2011&subject=0-AEO2011&table=51-AEO2011&region=0-0&cases=ref2011-d020911a

[13] Sorrell, S. and J. Dimitropoulos, 2007. "UKERC Review of Evidence for the Rebound Effect, Technical Report 2: Econometric Studies", UKERC/WP/TPA/2007/010, UK Energy Research Centre, London, October and Greening, L.A., D.L. Greene and C. Difiglio, 2000. "Energy Efficiency and Consumption – The Rebound Effect – A Survey", Energy Policy, vol. 28, pp. 389-401. (Docket EPA-HQ-OAR-2010-0799)

[14] Pickrell, D. and P. Schimek, 1999. "Growth in Motor Vehicle Ownership and Use: Evidence from the Nationwide Personal Transportation Survey," Journal of Transportation and Statistics, vol. 2, no. 1, pp. 1-17. (Document ID EPA-HQ-OAR-2010-0799-0027)

[15] Puller, Steven and Lorna Greening. 1999. "Household Adjustment to Gasoline Price Change: An Analysis Using Nine Years of U.S. Survey Data," Energy Economics 21(1):37-52. (Docket EPA-HQ-OAR-2010-0799)

[16] Small, K. and K. Van Dender, 2007a. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect." The Energy Journal, vol. 28, no. 1, pp. 25-51. (Docket EPA-HQ-OAR-2010-0799)

[17] Small, K. and K. Van Dender, 2007b. "Long Run Trends in Transport Demand, Fuel Price Elasticities and Implications of the Oil Outlook for Transport Policy," OECD/ITF Joint Transport Research Centre Discussion Papers 2007/16, OECD, International Transport Forum. (Docket EPA-HQ-OAR-2010-0799)

[18] Report by Kenneth A. Small of University of California at Irvine to EPA, "The Rebound Effect from Fuel Efficiency Standards: Measurement and Projection to 2030,", June 12, 2009. (See docket: EPA-HQ-OAR-2010-0799)

[19] Hymel, Kent M., Kenneth A. Small, and Kurt Van Dender, "Induced demand and rebound effects in road transport," Transportation Research Part B: Methodological, Volume 44, Issue 10, December 2010, Pages 1220-1241, ISSN 0191-2615, DOI: 10.1016/j.trb.2010.02.007. (Docket EPA-HQ-OAR-2010-0799)

[20]Greene, David, 2012. "Rebound 2007: Analysis of U.S. light-duty vehicle travel statistics," Energy Policy, vol. 41, pp. 14-28. (Docket EPA-HQ-OAR-2010-0799)

[21] Gillingham, Kenneth. "The Consumer Response to Gasoline Price Changes: Empirical Evidence and Policy Implications." Ph.D. diss., Stanford University, 2011. (Document ID EPA-HQ-OAR-2010-0799-0760). The California Air Resources Board submitted this work for independent academic review in September 2011 and the three reviewers found the results and conclusions to be valid and reasonable. These reviews are available in Docket EPA-HQ-OAR-2010-0799 under the title, California Air Resources Board Independent Academic

Review of Gillingham, Kenneth. “The Consumer Response to Gasoline Price Changes: Empirical Evidence and Policy Implications.” Ph.D. diss., Stanford University, 2011.

[22] Dargay, J.M.,Gately,D.,1997. “The demand for transportation fuels: imperfect price-reversibility?,” Transportation Research PartB 31(1). (Docket EPA-HQ-OAR-2010-0799)

[23] Sentenac-Chemin, E.,2012. “Is the price effect on fuel consumption symmetric? Some evidence from an empirical study,” Energy Policy, vol. 41, pp. 59-65. (Docket EPA-HQ-OAR-2010-0799)

[24] Dermot Gately, 1993. "The Imperfect Price-Reversibility of World Oil Demand," The Energy Journal, International Association for Energy Economics, vol. 14(4), pp. 163-182. (Docket EPA-HQ-OAR-2010-0799)

[25] Bento, Antonio M., Lawrence H. Goulder, Mark R. Jacobsen, and Roger H. von Haefen, 2009, “Distributional and Efficiency Impacts of Increased US Gasoline Taxes,” *American Economic Review,* v. 99, pp. 1–37 and Su, Qing, 2012, “A Quantile Regresssion Analysis of the Rebound Effect: Evidence form the 2009 National Household Transportation Survey in the United States*,” Energy Policy,* v. 45, pp. 368-377. (Docket EPA-HQ-OAR-2010-0799)

[26] FHWA. 1997 *Federal Highway Cost Allocation Study*; http://www.fhwa.dot.gov/policy/hcas/final/index.htm (last accessed Sept. 9, 2011).

[27] Federal Highway Administration, 1997 *Federal Highway Cost Allocation Study*, http://www.fhwa.dot.gov/policy/hcas/final/index.htm, Tables V-22, V-23, and V-24 (last accessed Sept. 9, 2011).

[28] http://www.eia.gov/totalenergy/data/monthly/pdf/sec1_13.pdf

[29] http://www.eia.gov/totalenergy/data/monthly/pdf/sec1_13.pdf

[30] http://www.eia.gov/totalenergy/data/monthly/pdf/sec3_3.pdf

[31] http://www.eia.gov/totalenergy/data/monthly/pdf/sec3_3.pdf

[32] U.S. Department of Energy, Annual Energy Review, 2008, Report No. DOE/EIA-0384/2008 Tables 5.1 and 5.1c, June 26, 2009

[33] http://www.census.gov/foreign-trade/statistics/historical/gands.txt.

[34] Leiby, Paul N. "Estimating the Energy Security Benefits of Reduced U.S. Oil Imports," Oak Ridge National Laboratory, ORNL/TM-2007/028, Final Report, 2008.

[35] ORNL-TM-2007-028_Oil_Import_Premium_revisited_2008Mar14 Rev8.pdf, "Estimating the U.S. Oil Security Premium for the Proposed 2017-2025 Light -Duty Vehicle GHG/Fuel Economy Rule", Paul N. Leiby, Oak Ridge National Laboratory. March 2008.

[36] Ibid. References are in the back of the document.

[37] Estimating the U.S. Oil Security Premium for the Proposed 2017-2025 Light -Duty Vehicle GHG/Fuel Economy Rule", Paul N. Leiby, Oak Ridge National Laboratory (ORNL), July 15 2012

[38] Based on data from the CIA, combining various recent years, https://www.cia.gov/library/publications/the-world-factbook/rankorder/2176rank.html.

[39] IEA 2011 "IEA Response System for Oil Supply Emergencies".

[40] Transcript of Philadelphia Public Hearing, p. 175 (January 19, 2012).

[41] Center for Naval Analyses, "Ensuring America's Freedom of Movement: A National Security Imperative to Reduce U.S. Oil Dependence" October 2011.

[42] U.S. Department of Defense. 2010. Quadrennial Defense Review Report. Secretary of Defense: Washington, D.C. 128 pages.

[43] The Department of the Navy's Energy Goals (http://www.navy.mil/features/Navy_EnergySecurity.pdf) (Last accessed May 31, 2011).

[44] U.S. Department of Defense, Speech: Remarks at the White House Energy Security Summit. Tuesday, April 26, 2011. (http://www.defense.gov/speeches/speech.aspx?speechid=1556) (Last accessed May 31, 2011).

[45] Leiby, Paul. "Military Costs of Energy Security". 2012.

[46] Delucchi, Mark A. and James J. Murphy. "US military expenditures to protect the use of Persian Gulf oil for motor vehicles." Energy Policy 36, no. 6 (June 2008): 2253-2264. doi:10.1016/j.enpol.2008.03.006. http://linkinghub.elsevier.com/retrieve/pii/S0301421508001262.

[47] Crane, Keith, et al. "Does Imported Oil Threaten U.S. National Security?" RAND, 2009.

[48] Stern, RJ. "United States cost of military force projection in the Persian Gulf, 1976–2007", Energy Policy, 2010.

[49] EPA MOVES model ver 2010a (http://www.epa.gov/otaq/models/moves/index.htm).

[50] Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions from Transportation (GREET) Model*, Version 1.8, June 2007, *available at* http://greet.es.anl.gov/ (last accessed Sept. 9, 2011).

[51] Calculation of Upstream Emissions for the Greenhouse Gas (GHG) Vehicle Rule, Memorandum from Craig A. Harvey to Docket EPA-HQ-OAR-2009-0472, September 14, 2009

[52] Calculation of Upstream Emissions for the Greenhouse Gas (GHG) Vehicle Rule, Memorandum from Craig A. Harvey to Docket EPA-HQ-OAR-2009-0472, September 14, 2009

[53] The issue is discussed in more detail in the PM NAAQS RIA from 2006. See U.S. Environmental Protection Agency. 2006. Final Regulatory Impact Analysis (RIA) for the Proposed National Ambient Air Quality Standards for Particulate Matter. Prepared by: Office of Air and Radiation. October 2006. Available at http://www.epa.gov/ttn/ecas/ria.html.

[54] U.S. Environmental Protection Agency (U.S. EPA), 2010. Regulatory Impact Analysis, Final Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. Office of Transportation and Air Quality. April. Available at http://www.epa.gov/otaq/climate/regulations/420r10009.pdf. EPA-420-R-10-009

[55] U.S. Environmental Protection Agency (U.S. EPA). 2008. Regulatory Impact Analysis, 2008 National Ambient Air Quality Standards for Ground-level Ozone, Chapter 6. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available at <http://www.epa.gov/ttn/ecas/regdata/RIAs/6-ozoneriachapter6.pdf>. EPA-HQ-OAR-2009-0472-0238

[56] U.S. Environmental Protection Agency (U.S. EPA). 2010. Regulatory Impact Analysis: National Emission Standards for Hazardous Air Pollutants from the Portland Cement Manufacturing Industry. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Augues. Available on the Internet at < http://www.epa.gov/ttn/ecas/regdata/RIAs/portlandcementfinalria.pdf >. EPA-HQ-OAR-2009-0472-0241

[57] U.S. Environmental Protection Agency (U.S. EPA). 2010. Final NO2 NAAQS Regulatory Impact Analysis (RIA). Office of Air Quality Planning and Standards, Research Triangle Park, NC. April. Available on the Internet at http://www.epa.gov/ttn/ecas/regdata/RIAs/FinalNO2RIAfulldocument.pdf. Accessed March 15, 2010. EPA-HQ-OAR-2009-0472-0237

[58] U.S. Environmental Protection Agency (U.S. EPA). 2008. Technical Support Document: Calculating Benefit Per-Ton estimates, Ozone NAAQS Docket #EPA-HQ-OAR-2007-0225-0284. Office of Air Quality Planning and Standards, Research Triangle Park, NC. March. Available on the Internet at <http://www.regulations.gov>. EPA-HQ-OAR-2009-0472-0228

[59] Fann, N. et al. (2009). The influence of location, source, and emission type in estimates of the human health benefits of reducing a ton of air pollution. Air Qual Atmos Health. Published online: 09 June, 2009. EPA-HQ-OAR-2009-0472-0229

[60] Pope, C.A., III, R.T. Burnett, M.J. Thun, E.E. Calle, D. Krewski, K. Ito, and G.D. Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate

Air Pollution." Journal of the American Medical Association 287:1132-1141. EPA-HQ-OAR-2009-0472-0263

[61] Laden, F., J. Schwartz, F.E. Speizer, and D.W. Dockery. 2006. "Reduction in Fine Particulate Air Pollution and Mortality." American Journal of Respiratory and Critical Care Medicine 173:667-672. Estimating the Public Health Benefits of Proposed Air Pollution Regulations. Washington, DC: The National Academies Press. EPA-HQ-OAR-2009-0472-1661

[62] Mrozek, J.R., and L.O. Taylor. 2002. "What Determines the Value of Life? A Meta-Analysis." Journal of Policy Analysis and Management 21(2):253-270. EPA-HQ-OAR-2009-0472-1677

[63] Viscusi, V.K., and J.E. Aldy. 2003. "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World." Journal of Risk and Uncertainty 27(1):5-76. EPA-HQ-OAR-2009-0472-0245

[64] Kochi, I., B. Hubbell, and R. Kramer. 2006. An Empirical Bayes Approach to Combining Estimates of the Value of Statistical Life for Environmental Policy Analysis. Environmental and Resource Economics. 34: 385-406. EPA-HQ-OAR-2009-0472-0235

[65] U.S. Environmental Protection Agency (U.S. EPA). 2000. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available on the Internet at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/cover.pdf>. EPA-HQ-OAR-2009-0472-0226

[66] Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions from Transportation (GREET) Model*, Version 1.8, June 2007, *available at* http://www.transportation.anl.gov/software/GREET/index.html (last accessed April 20, 2008).

[67] Docket ID EPA-HQ-OAR-2009-0472-114577, *Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon*, with participation by Council of Economic Advisers, Council on Environmental Quality, Department of Agriculture, Department of Commerce, Department of Energy, Department of Transportation, Environmental Protection Agency, National Economic Council, Office of Energy and Climate Change, Office of Management and Budget, Office of Science and Technology Policy, and Department of Treasury (February 2010). Also available at http://epa.gov/otaq/climate/regulations.htm

[68] Marten, A. and S. Newbold. 2011. "Estimating the Social Cost of Non-CO2 GHG Emissions: Methane and Nitrous Oxide." NCEE Working Paper Series #11-01. http://yosemite.epa.gov/ee/epa/eed.nsf/WPNumber/2011-01?opendocument. Accessed May 24, 2012.

[69] *Id.*

[70] Office of Management and Budget, Circular A-4, "Regulatory Analysis," September 17, 2003, 33. *Available at* http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf (last accessed July 24, 2009).

[71] *Id.*

Chapter 5: Air Conditioning, Off-Cycle Credits, and Other Flexibilities

5.1 Air conditioning technologies and credits

5.1.1 Overview

Air conditioning (A/C) is virtually standard equipment in new cars and trucks, as over 95% of the new cars and light trucks in the United States are equipped with mobile air conditioning (or MAC) systems. Given the large penetration of A/C in today's light duty vehicle fleet, its impact on the amount of energy consumed is significant. In the MYs 2012-2016 Light-Duty Greenhouse Gas Rule, EPA structured the rule to allow vehicle manufacturers' to generate credits for improved air conditioner systems in complying with the CO_2 fleetwide average standards and accounted for these AC improvements in determining the stringency of the GHG standards. EPA will continue with and expand upon these provisions, and manufacturers can generate credits for improved performance of both direct (A/C leakage) and indirect (tailpipe emissions attributable to A/C use) A/C emissions. In addition, EPA is acting pursuant to its authority under EPCA to allow manufacturers to generate fuel consumption improvement values for purposes of CAFE compliance based on the use of A/C efficiency-improving technologies. In the 2012-2016 rule, EPA and NHTSA did not allow manufacturers to include reductions in fuel consumption resulting from A/C efficiency improvements) in the CAFE calculations. As was the case in the MYs 2012-2016 rule, manufacturers do not to count reductions in A/C leakage toward their CAFE calculations since these improvements do not affect fuel economy. In the sections below, the agencies will first describe the structure of the EPA A/C program, followed by a description of the A/C program under CAFE.

Through model years 2012-2016, EPA expects that all manufacturers will generate A/C credits offered (for reduced leakage and improved efficiency) to help come into compliance with the standards. EPA estimated that there would be significant penetration of A/C technologies to gain credits, and this was reflected in the stringency of the standards.[a] Consistent with the 2008-based fleet definitions, the base level of A/C technologies in 2008 forms the A/C "baseline", and the A/C technologies projected to penetrate to the fleet in 2016 is referred to as the A/C "reference". For this MYs 2017-2025 rule, EPA will maintain the credit program the amount of credit being determined in relation to the MY 2008 baseline . The credits should continue to the present rule since without them, a manufacturer utilizing credits in MY 2016 could suddenly find in MY 2017 that the stringency of the standards are artificially increased due to discontinued A/C credits.[b] In this chapter, A/C credits are

[a] NHTSA will also be referencing these efficiency improving A/C technologies in its rule, referring to them as "fuel consumption improvements."

[b] Put another way, the MY 2016 GHG standards would remain even if there were no new MY 2017-2025 standards and A/C credits would also continue. Thus, if the AC credits were removed or significantly changed from these (perpetuated) post-2016 standards, the stringency of those standards would effectively be increased.

calculated from the 2008 baseline vehicle fleet (though there are some changes to the credit program), while costs are calculated from the 2008 model year based reference fleet. Any additional A/C credits projected for MYs 2017-2025 are reflected in the stringency of the standards as described in Section III.C.1 of the preamble.

A/C is different from the other technologies described in Chapter 3 of the joint TSD in several ways. First, most of the technologies described earlier directly affect the efficiency of the engine, transmission, and vehicle systems. As such, these systems are almost always active while the vehicle is moving down the road or while being tested on a dynamometer for the fuel economy and emissions test drive cycles. A/C, on the other hand, is a parasitic load on the engine that only burdens the engine when the vehicle occupants demand it. Since it is not tested as a part of the fuel economy and GHG emissions standards compliance test drive cycles (the A/C system is off while the vehicle is operated on the two test cycles -- the FTP and HFET -- used for compliance purposes) it is referred to as an “off-cycle” effect. There are many other off-cycle loads that can be switched on by the occupant that affect the engine; these include lights, wipers, stereo systems, electrical defroster/defogger, heated seats, power windows, etc. However, these electrical loads individually amount to a very small effect on the engine (although together they can be significant). The A/C system (by itself) adds a significant load on the engine (especially on sunny, hot, and/or humid days), resulting in increased fuel consumption, or “indirect” CO_2 emissions.

There are two mechanisms by which A/C systems contribute to the emissions of greenhouse gases. The first is through direct leakage of the refrigerant into the air. The hydrofluorocarbon (HFC) refrigerant compound currently used in all recent model year vehicles is R-134a (also known as 1,1,1,2-Tetrafluoroethane, or HFC-134a). Based on the higher global warming potential of HFCs, a small leakage of the refrigerant has a greater global warming impact than a similar amount of emissions of some other mobile source GHGs. R-134a has a global warming potential (GWP) of 1,430. This means that 1 gram of R-134a has the equivalent global warming potential of 1,430 grams of CO2 (which has a GWP of 1). In order for the A/C system to take advantage of the refrigerant’s thermodynamic properties and to exchange heat properly, the system must be kept at high pressures even when not in operation. Typical static pressures can range from 50-80 psi depending on the temperature, and during operation, these pressures can get to several hundred psi. At these pressures leakage can occur through a variety of mechanisms. The refrigerant can leak slowly through seals, gaskets, and even small failures in the containment of the refrigerant. Through normal use, the rate of leakage may also increase due to wear on the system components. Leakage may also increase more quickly through rapid component deterioration such as during vehicle accidents, maintenance or end-of-life vehicle scrappage (especially when refrigerant capture and recycling programs are less efficient). Small amounts of leakage can also occur continuously even in extremely “leak-tight” systems by permeating through hose membranes and seals. This last mechanism is not dissimilar to fuel permeation through porous fuel lines (and seals). Manufacturers may be able to reduce these leakage emissions through the implementation of technologies/designs such as leak-tight, non-porous, durable components. The global warming impact of leakage emissions also can be addressed by using alternative refrigerants, such as HFO-1234yf, R-744 (CO2), HFC-152a (R-152a), or other refrigerants under development with lower global warming potentials than R -134a. Refrigerant emissions can also occur during maintenance and at the end of the vehicle's life (as well as emissions during the initial charging of the system with refrigerant), and these emissions are already addressed by the CAA Title VI stratospheric ozone program, as described below.[c]

The second mechanism by which vehicle A/C systems contribute to GHG emissions is through the consumption of additional fuel required to provide power to the A/C system and from carrying around the weight of the A/C system hardware year-round. These indirect emissions result from the additional fuel which is required to provide power to the A/C system (and the additional fuel is converted into CO_2 by the engine during combustion). These increased emissions due to A/C operation can be reduced by increasing the overall efficiency of the vehicle's A/C system, as described below. The final rules do not provide credits for the weight of the A/C system, since the incremental increase in CO_2 emissions and fuel consumption due to carrying the A/C system is directly measured during the normal (2-cycle) federal test procedure, and is thus already accounted for in the CO_2 tailpipe standard.

EPA's analysis from the MYs 2012-2016 rule indicates that A/C-related indirect emissions represent about 3.9% of the total greenhouse gas emissions from cars and light trucks. In this document, EPA will separate the discussion of these two categories of A/C-related emissions because of the fundamental differences in the emission mechanisms and the methods of emission control. Refrigerant leakage control is akin in many respects to past EPA fuel evaporation control programs (in that containment of a fluid is the key feature), while efficiency improvements are more similar to the vehicle-based control of CO_2 using the technologies described in chapter 3 of the joint TSD in that emission reductions would be achieved through specific hardware and controls. Finally, the accounting for credits for control of direct and indirect A/C improvement credits is independent, which allows for a separate discussion of these two categories.

5.1.2 Air Conditioner Leakage

5.1.2.1 Impacts of Refrigerant Leakage on Greenhouse Gas Emissions

There have been several studies in the literature which have attempted to quantify the emissions (and impact) of air conditioner HFC emissions from light duty vehicles. In this section, several of these studies are discussed. These inventories and impacts form the basis for the air conditioner environmental credits, and in this final rule, we are using the same emissions inventory and analysis method for refrigerant leakage as we did in the 2012-2016 rule as described in section 5.1.2.3.3.

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[c] Even if A/C systems utilize a "low-GWP" refrigerant, such as HFO-1234yf (GWP = 4), emissions are still a concern. First, as refrigerant leaks from the system, once the refrigerant level drops to 40 to 50 percent of its normal capacity, the operating efficiency of the system will degrade, resulting in an increase in fuel consumption due to A/C use, and an increase in indirect emissions. Second, if systems do leak refrigerant at an excessive rate, there is a higher probability that someone will unlawfully recharge the system with a cheaper, and higher-GWP refrigerant, resulting in increased direct emissions.

Based on measurements from 300 European vehicles (collected in 2002 and 2003), Schwarz and Harnisch estimate that the average HFC direct leakage rate from modern A/C systems was 53 g/yr.[1] This corresponds to a leakage rate of 6.9% per year. This was estimated by extracting the refrigerant from recruited vehicles and comparing the amount extracted to the amount originally filled (as per the vehicle specifications). The fleet and size of vehicles differs from Europe and the United States, therefore it is conceivable that vehicles in the United States could have a different leakage rate. The authors measured the average charge of refrigerant at initial fill to be about 747 grams (it is somewhat higher in the U.S. at 770g), and that the smaller cars (684 gram charge) emitted less than the higher charge vehicles (883 gram charge). Moreover, due to the climate differences, the A/C usage patterns also vary between the two continents, which may influence leakage rates.

Vincent et al., from the California Air Resources Board estimated the in-use refrigerant leakage rate to be 80 g/yr.[2] This value is based on the consumption of refrigerant in commercial fleets, and surveys of vehicle owners and technicians. The study assumed an average A/C charge size of 950 grams and a recharge rate of 1 in 16 years (lifetime). The recharges occurred when the system was 52% empty and the fraction recovered at end-of-life was 8.5%.

5.1.2.1.1 Emission Inventory

The EPA publishes an inventory of greenhouse gases and sinks on an annual basis. The refrigerant emissions numbers that are used in the present analysis are from the Vintaging model, which is used to generate the emissions included in this EPA inventory source. The HFC refrigerant emissions from light duty vehicle A/C systems was estimated to be 61.8 Tg CO_2 equivalent in 2005 by the Vintaging model.[3,d] In 2005, refrigerant leakage accounted for about 5.1% of total greenhouse gas emissions from light duty sources. From a vehicle standpoint, the Vintaging model assumes that 42% of the refrigerant emissions are due to direct leakage (or “regular” emissions), 49% for service and maintenance (or “irregular” emissions), and 9% occurs at disposal or end-of-life as shown in the following table. These are based on assumptions of the average amount of chemical leaked by a vehicle every year, how much is lost during service of a vehicle (from professional service center and do-it-yourself practices), and the amount lost at disposal. These numbers vary somewhat over time based on the characteristics (e.g. average charge size and leakage rate) of each “vintage” of A/C system, assumptions of how new A/C systems enter the market, and the number of vehicles disposed of in any given year.

Table 5-1 Light Duty Vehicle HFC-134a Emissions in 2005 from Vintaging Model - HFC Emissions Multiplied by 1430 GWP to Convert to CO_2 Equivalent

Emission Process	HFC emissions (metric tons)	Fraction of total

[d] EPA reported the MVAC emissions at 56.6 Tg CO_2 EQ, using a GWP of 1300. This number has been adjusted using a GWP of 1430.

Leakage	18,151	0.42
Maintenance/servicing	21,176	0.49
Disposal/end-of-life	3,890	0.09
Total	43,217	1.0

5.1.2.2 Alternative Refrigerants

Leakage emissions can also be reduced with the use of refrigerants other than R-134a, which has a global warming potential (GWP) of 1430. To address future GHG regulations in the Europe Union and the State of California, air conditioning systems which use alternative refrigerants are under development, and have been demonstrated in prototypes by vehicle manufacturers and A/C component suppliers. The European Union has enacted regulations which require the use of refrigerants with a GWP less than 150. Phase-in of these EU regulations began with new vehicle platforms in MY 2011, and will be completely phased-in for all vehicles by MY 2017. Some of the alternative refrigerants under development by manufacturers and A/C component suppliers include HFO-1234yf, CO_2, HFC-152a, and low-GWP blends of existing refrigerants. The air conditioning component and refrigerant manufacturers, as well as automotive manufacturers, are actively studying the performance, efficiency, safety, and cost of these alternative refrigerants.

HFO-1234yf, with a GWP of 4, is a leading candidate as an alternative to R-134a refrigerant. For example, General Motors has selected HFO1234yf for use in certain model year 2013 vehicles.[4] While the performance and efficiency of A/C systems using HFO-1234yf can be equivalent to those using HFC-134a, the higher cost of implementing this refrigerant – estimated at $67 (2010$, direct manufacturing cost) per vehicle in model year 2016 (see section 5.1.4) – is causing the industry to consider other solutions which are lower-cost.

A so-called “natural refrigerant” under consideration is CO_2, which has a GWP of 1. While this refrigerant is environmentally neutral from a GWP perspective (i.e. relative to a CO_2 baseline), and is currently used in some commercial refrigeration units, its use in automotive applications is challenging due to the higher operating pressure of CO_2 systems, where the peak pressure can be as high as 2000 PSI, compared to the peak pressure in HFC-134a systems of around 450 PSI. Several European auto manufacturers have successfully developed CO_2 A/C systems, but none have been produced for use in new vehicles at this time. An A/C system which uses CO_2 is estimated to cost from about $140 to $210 more than an equivalent HFC-134a system; however, the cost of the refrigerant itself is expected to be considerably less than HFO-1234yf.[5]

HFC-152a (1,1-difluoroethane) is a flammable refrigerant with a GWP of 120 and an ASHRAE flammability designation of Class 2. Given the flammability of this refrigerant, we expect that manufacturers would either need to design their A/C systems with a secondary loop or with directed relief valves to mitigate safety concerns within the cabin area, and to comply with the use conditions at 40 CFR Part 82 Subpart G Appendix B. With a secondary loop design, the evaporator is not located inside the passenger cabin area, but inside a chiller in an underhood location, where a secondary fluid (such as an ethylene glycol-water mixture) is circulated to transfer heat from the cabin to the chiller. This approach requires additional system components (chiller, pump, reservoir, and plumbing for secondary loop), which adds an estimated 12 lbs. of mass to the vehicle.[6] Secondary loop systems have added value in that they have the ability to store cooling within the loop, which in turn allows for "free" cooling to occur during deceleration events, and then delivered to the cabin during engine idle off conditions (for example). With the directed relief valve design, the refrigerant within the A/C system is vented and ducted to the atmosphere by opening high and low-side relief valves when a leak is detected.[7] The advantage of the directed relief valve approach (relative to a secondary loop) is that fewer components are needed, potentially minimizing the mass and cost of the system.

Other alternative refrigerants which may be used in the future may include low-GWP blends. Recent studies have shown that the low-GWP refrigerant blends AC5 and AC6 from the chemical manufacturer Mexichem, have performance and efficiency characteristics which are similar to HFC-134a under high-load (maximum cooling) conditions, and slightly reduced performance and efficiency under low-load conditions. These mildly-flammable (similar to HFO-1234yf) refrigerant blends, being comprised of several different refrigerant components, have zeotropic properties. This means that the fraction of each component in the gas and liquid phases is not constant, and varies with temperature and pressure within the system.[8] Zeotropic behavior may result in mal-distribution of the refrigerant within the evaporator and condenser, which negatively affects system efficiency, especially at low loads.[9] However, it is believed that optimization of evaporator and condenser design can improve the low-load efficiency. These blends may be similar enough in performance and in their physical characteristics to HFC-134a and HFO-1234yf that they may be used in current production A/C systems designs with relatively minor modifications

We expect that stakeholders in the automotive A/C industry will continue to study and develop low-GWP refrigerant solutions in order to minimize the direct and indirect impact of A/C-related emissions. With the statutory requirements for low-GWP refrigerants in the European Union, which began in model year 2011 for new vehicles designs, we expect that one or more of these low-GWP solutions will be available for at least 20% of the U.S. vehicle fleet by model year 2017, and that an additional 20% of the fleet can adopt the alternative refrigerant in each subsequent model year. EPA expects that manufacturers would be changing over to alternative refrigerants at the time of complete vehicle redesign, which occurs about every 5 years, though in confidential meetings, some manufacturers/suppliers have informed EPA that it may be possible to modify the hardware for some alternative refrigerant systems between redesign periods.

5.1.2.3 A/C Leakage Credit

The level to which each technology can reduce leakage can be estimated using the February 2012 version of SAE Surface Vehicle Standard J2727 – HFC-134a Mobile Air Conditioning System Refrigerant Emission Chart. While this standard was developed for leakage of HFC-134a refrigerant, it is also applicable to the alternative refrigerant HFO-1234yf, and may be applicable to other low-GWP refrigerants as well. To convert J2727 chart emission (leak) rates from HFC-134a to HFO-1234yf leakage rates, the result is multiplied by 1.03. This conversion factor for HFO-1234yf is derived by multiplying the ratio of the molecular weights of the two refrigerants (114 kg/kmol for HFO-1234yf and 102 kg/kmol for HFC-134a) by the inverse ratio of the dynamic viscosities of the two refrigerants (11.1 x 10-6 Pa·s for HFC-134a and 12.0 x 10-6 Pa·s for HFO-1234yf).

The J2727 standard was developed by SAE and the cooperative industry and government IMAC (Improved Mobile Air Conditioning) program using industry experience, laboratory testing of components and systems, and field data to establish a method for calculating leakage. With refrigerant leakage rates as low as 10 g/yr, it would be exceedingly difficult to measure such low levels in a test chamber (or shed). Since the J2727 method has been correlated to "mini-shed", or SAE J2763, results (where A/C components are tested for leakage in a small chamber, simulating real-world driving cycles), the EPA considers this method to be an appropriate surrogate for vehicle testing of leakage.[10] It is also referenced by the California Air Resources Board in their Environmental Performance Label regulation and the State of Minnesota in their GHG reporting regulation.[11,12]

5.1.2.3.1 Why Is EPA Continuing to Rely on a Design-Based Approach to Quantify Leakage?

EPA is not reopening, reconsidering, or otherwise reevaluating its approach to quantifying A/C leakage in the MYs 2012-2016 final rule. However, as in the MYs 2012-2016 rule, EPA will continue to use a design-based method for quantifying refrigerant leakage from A/C systems. In the time since the MYs 2012-2016 rule was finalized, the Agency was not informed of any new approaches or methods for measuring actual refrigerant leak rates. While EPA generally prefers performance testing for emissions, a feasible method for measuring refrigerant emissions accurately from a vehicle is not available, and we are finalizing for MYs 2017-2025 a continuation of the SAE J2727-based approach adopted in the MYs 2012-2016 rule. EPA believes that the SAE J2727 method, as discussed below, is an appropriate method for quantifying the expected yearly refrigerant leakage rate from A/C systems.

5.1.2.3.2 How Will Leakage Credits Be Calculated?

For model years 2017 through 2025, the A/C credit available to manufacturers will be calculated based on how much a particular vehicle's annual leakage value is reduced compared to an average MY 2008 vehicle with baseline levels of A/C leakage technology, and will be calculated using a method drawn directly from the updated SAE J2727 approach (for details on these updates, see 5.1.2.3.2.2). By scoring the minimum leakage rate possible on the J2727 components enumerated in the rule (expressed as a measure of annual leakage), a manufacturer can generate the maximum A/C credit (on a gram per mile basis). To avoid backsliding on leakage rates when using low-GWP refrigerants, where manufacturers could choose less costly sealing technologies and/or materials, EPA is finalizing the proposed disincentive credit for "high leak" on alternative refrigerant systems. The maximum value for this high leak disincentive credit (or HiLeakDisincentive) is 1.8 g/mi for cars and 2.1 g/mi for trucks, with lower amounts possible for leakage rates between the minimum leakage score (MinScore) and the average impact (AvgImpact). The terms used for calculating the A/C Leakage Credit as well as the HiLeakDisincentive are discussed later in this section.

The A/C credit available to manufacturers will be calculated based on the reduction to a vehicle's yearly leakage rate, using the following equation for HFC-134a refrigerant:

Equation 5-1 Credit Equation for HFC-134a Refrigerant

*A/C Leakage Credit = (MaxCredit) * [1 - (§86.166-12 Score / AvgImpact[e]) * (GWPRefrigerant / 1430)]*

and the following equation for low-GWP, alternative refrigerants:

Equation 5-2 Credit Equation for Alternative Refrigerants

*A/C Leakage Credit = (MaxCredit) * [1 - (§86.166-12 Score / AvgImpact[e]) * (GWPRefrigerant / 1430)] - HiLeakDisincentive*

where the HiLeakDisincentive is determined in accordance with one of the following three conditions, depending on the refrigerant capacity (RefrigCapacity), or charge level, of the A/C system:

For A/C systems with a refrigerant capacity <= 733g:

$$HiLeakDis = 0.0, if\ Score \leq 11.0\ g/yr$$

$$HiLeakDis = 1.8\ or\ 2.1 * \left(\frac{Score - 11}{3.3}\right), if\ 11.0 < Score \leq 14.3,$$

$$HiLeakDis = 1.8, if\ Score > 14.3$$

For A/C systems with a refrigerant capacity > 733g:

$$HiLeakDis = 0.0, if\ Score \leq RefrigCapacity * 0.015$$

$$HiLeakDis = 1.8 * (Score - (RefrigCapacity * 0.015)/3.3), if\ RefrigCapacity * 0.015 < Score \leq RefrigCapacity * 0.015 + 3.3$$

$$HiLeakDis = 1.8, if\ Score > RefrigCapacity * 0.015 + 3.3$$

There are four significant terms to the credit equation. Each is briefly summarized below, and is then explained more thoroughly in the following sections. Please note that the values of

[e] Section 86.166-12 sets out the individual component leakage values based on the SAE value.

many of these terms change depending on whether HFC-134a or an alternative refrigerant is used. The values are shown in Table 5-2, and are documented in the following sections.

- "MaxCredit" is a term for the maximum amount of credit entered into the equation before constraints are applied to terms. The maximum credits that could be generated by a manufacturer is limited by the choice of refrigerant and by assumptions regarding maximum achievable leakage reductions. Some of these values may have changed since the 2012-2016 rule.
- "Score" is the leakage score of the A/C system as measured according to the §86.166-12 calculation in units of g/yr, where the minimum score which is deemed feasible is fixed.
- "AvgImpact" is a term which represents the annual average impact of A/C leakage.
- "MinScore" is the lowest leak score that EPA projects is possible, when starting from a baseline, or AvgImpact, system. The MinScore represents a 50% reduction in leakage from the baseline levels based on the feasibility analysis detailed below.
- "GWPRefrigerant" is the global warming potential for direct radiative forcing of the refrigerant as defined by EPA (or IPCC).
- "HiLeakDisincentive" is a term for the disincentive credit deducted for low-GWP alternative refrigerant systems which have a leakage rate greater than the minimum leakage score of 11.0 g/year for cars and trucks. The maximum Disincentive is 1.8 g/mile for cars and 2.1 g/mile for trucks. The 11.0 g/year threshold for generating a HiLeakDisincentive is based on the analysis we used for the MY 2014-2018 GHG Emissions Standards for Heavy-Duty Engines and Vehicles, where a maximum refrigerant leak rate standard of 11.0 g/year was set for vehicles with a refrigerant capacity of 733 g or lower, and 1.5 percent of the refrigerant capacity (in grams) for systems with a refrigerant capacity greater than 733 g. .

Table 5-2 Components of the A/C Credit Calculation

	HFC-134a		Lowest-GWP Refrigerant (GWP=1)	
	Cars	Trucks	Cars	Trucks
MaxCredit equation input (grams/mile CO_2 EQ)	12.6	15.6	13.8	17.2
A/C credit maximum (grams/mile CO_2 EQ)[a]	6.3	7.8	13.8	17.2
§86.166-12 MinScore (grams HFC/year)	8.3	10.4	8.3	10.4
Avg Impact (grams HFC/year)	16.6	20.7	16.6	20.7

[a] With electric compressor, value increases to 9.5 and 11.7 for cars and trucks, respectively.

5.1.2.3.2.1 Max Credit Term

In order to determine the maximum possible credit on a gram per mile basis, it was necessary to determine the projected real world HFC emissions per mile. This calculation is done exactly the same as it was done for the MYs 2012-2016 final rule. Because HFC is a leakage type of emission, it is largely disconnected from vehicle miles traveled (VMT).[f] Consequently, EPA calculated the total HFC inventory (in 2016), and then calculated the VMT for that year separately. The quotient of these two terms is the HFC contribution per mile.

Consistent with the methodology presented in the MYs 2012-2016 rule, the HFC emission inventories were estimated from a number of existing data sources. The per-vehicle per-year HFC emission of the current vehicle fleet was determined using averaged 2005 and 2006 registration data from the Transportation Energy Databook (TEDB) and 2005 and 2006 mobile HFC leakage estimates from the EPA Emissions and Sinks report described above.3[,13] The per-vehicle per-year emission rates were then adjusted to account for the new definitions of car and truck classes by increasing the car contribution proportionally by the percentage of former trucks that are reclassified as cars.[g] This inventory calculation assumes that the leakage rates and charge sizes of future fleets (absent any standards) are equivalent to the fleet present in the 2005/2006 reference years. Preliminary EPA analysis indicates that this may increasingly overstate the future HFC inventory, as charge sizes are decreasing, though more is discussed on this topic below.

The per-vehicle per-year average emission rate was then scaled by the projected vehicle fleet in each future year (using the fleet predicted in the emissions analysis) to estimate the HFC emission inventory if no further controls were enacted on the fleet. After dividing the 2016 inventory by total predicted VMT in 2016, an average per mile HFC emission rate ("base rate") was obtained.

The base rate is an average in-use number, which includes both old vehicles with significant leakage, as well as newer vehicles with very little leakage. The new vehicle leakage rate is discussed in section 5.1.2.4, while deterioration is discussed in section 5.1.2.6.

- Max Credit with Conventional Refrigerant (HFC-134a)
  Two adjustments were made to the base rate in order to calculate the Maximum HFC credit with conventional refrigerant. First, EPA has determined that 50% leakage prevention is the maximum potentially feasible prevention rate in the timeframe of this rule (see section 5.1.2.4). Some leaks will occur and are expected, regardless of prevention efforts. The accuracy of the J2727 approach (as expressed in §86.112), as a design based test, decreases as the amount of expected leakage diminishes. 50% of the base rate is therefore set as the maximum potential leakage credit for improvements to HFC leakage using conventional refrigerant.

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[f] In short, leakage emissions occur even while the car is parked, so the connection to a gram/mile credit is not straightforward. However, HFC emissions must be converted to a gram/mile basis in order to create a relevant credit.

[g] Many of these "older" references still use the old definition of car and truck. The new definitions do not apply until model year 2011.

Second, EPA expects that improvements to conventional refrigerant systems will affect both leakage and service emissions, but will not affect end of life emissions. EPA expects that reductions in the leakage rate from A/C systems will result in fewer visits for maintenance and recharges. This will have the side benefit of reducing the emissions leftover from can heels (leftover in the recharge cans) and the other releases that occur during maintenance. However, as disposal/end of life emissions will be unaffected by the leakage improvements (and also are subject to control under the rules implementing Title VI of the CAA), the base rate was decreased by a further 9% (Table 5-1).

- Max Credit with Alternative Refrigerant
  Emission reductions greater than 50% are possible with alternative refrigerants. As an example, if a refrigerant with a GWP of 0 were used, it would be possible to eliminate all refrigerant GHG emissions. In addition, for alternative refrigerants, the EPA believes that vehicles with reduced GWP refrigerants should get credit for end of life emission reductions. Thus, the maximum credit with alternative refrigerant is about 9% higher than twice the maximum leakage reduction.

As discussed above, EPA recognizes that substituting a refrigerant with a significantly lower GWP will be a very effective way to reduce the impact of all forms of refrigerant emissions, including maintenance, accidents, and vehicle scrappage.

The A/C Leakage Credits that will be available will be a function of the GWP of the alternative refrigerant as well as of leakage, with the largest credits being available for refrigerants with GWPs at or approaching a value of 1, while also maintaining a low leakage rate. For a hypothetical alternative refrigerant with a GWP of 1 (e.g., CO_2 as a refrigerant), effectively eliminating leakage as a GHG concern, our credit calculation method could result in maximum credits equal to total average emissions, or credits of 13.8 and 17.2 g/mi CO_2eq for cars and trucks, respectively, as incorporated into the A/C Leakage Credit formula above as the "MaxCredit" term.

As we did for the MYs 2012-2017 rule, EPA made a final adjustment to each credit to account for the difference between real-world HFC emissions and test-cycle CO_2 emissions. It has been shown that the tests currently used for CAFE certification represents an approximately 20% gap from real world fuel consumption and the resulting CO_2 emissions.[14] Because the credits from direct A/C improvements are taken from a real world source, and are being traded for an increase in fuel consumption due to increased CO_2 emissions, the credit was multiplied by 0.8 to maintain environmental neutrality (Table 5-3).

Table 5-3 HFC Credit Calculation for Cars and Trucks Based on a GWP of 1430

	HFC Inventory (MMT CO_2 EQ)	VMT (Billions of Miles)	Total HFC EmissionsPer Mile (CO_2 EQ Gram/mile)	HFC Leakage and Service EmissionsPer Mile (CO_2 EQ	Maximum Credit w/ alternative refrigerant (Adjusted for On-	Maximum Credit w/o alternative refrigerant (50% of Adjusted

				Gram/mile)	road gap & including end of life)	HFC & excluding end of life)
Car	27.4	1,580	17.2	15.5	13.8	6.3
Truck	30.4	1,392	21.5	19.6	17.2	7.8
Total	57.8	2,972	18.6	16.9	14.9	6.8

5.1.2.3.2.2 Section 86.166-12, implementing the J2727 Score Term

The J2727 score is the SAE J2727 yearly leakage estimate of the A/C system as calculated according to the J2727 procedure. In the time since the MYs 2012-2016 Light-Duty GHG Rule, there have been several refinements to the J2727 procedure which EPA has incorporated into the EPA regulations. First, a provision was made for system joints where 100 percent of the joints are leak test with helium and a mass-spectrometer leak detector. If the joints pass this leak test, they can be considered to have a leakage factor equivalent to that of a seal washer, which is next to the lowest factor possible for system joints. Second, a requirement was added to use SAE J2064 hose permeation test results in place of the discrete values for various hose material and construction types that were provided in previous versions of the J2727 test method. By using the test chamber results for refrigerant permeation through hoses, a more representative leakage estimate for the overall system is achieved. The minimum J2727 score for cars and trucks is a fixed value, and the section below describes the derivation of the minimum leakage scores that can be achieved using the J2727 procedure.

To calculate a J2727 score and credit for the alternative refrigerant HFO-1234yf, all values relevant to the credit calculations, as well as the J2727 score, shall be adjusted to account for the higher molecular weight of this refrigerant. In contrast to the studies discussed in section 5.1.2.6 which examines the HFC emission rate of the in-use fleet (which includes vehicles at all stages of life), the SAE J2727 estimates leakage from new vehicles. In the development of J2727, two relevant studies were assessed to quantify new vehicle emission rates. In the first study, measurements from relatively new (properly functioning and manufactured) Japanese-market vehicles were collected. This study was based on 78 in-use vehicles (56 single evap, 22 dual evap) from 7 Japanese auto makers driven in Tokyo and Nagoya from April, 2004 to December, 2005. The study also measured a higher emissions level of 16 g/yr for 26 vehicles in a hotter climate (Okinawa). This study indicated the leakage rate to be close to 8.6 g/yr for single evaporator systems and 13.3 g/yr for dual evaporator systems.[15] A weighted (test) average gives 9.9 g/yr. In the second study, emissions were measured on European-market vehicles up to seven years age driven from November, 2002 to January, 2003.[16] The European vehicle emission rates were slightly higher than the Japanese fleet, but overall, they were consistent. The average emission rate from this analysis is 17.0 g/yr with a standard deviation of 4.4 g/yr. European vehicles, because they have smaller charge sizes, likely understate the leakage rate relative to the United States. To these emission rates, the J2727 authors added a factor to account for occasional defective parts and/or improper assembly and to calibrate the result of the SAE J2727 calculation with the leakage measured in the vehicle and component leakage studies.

We adjust this rate up slightly by a factor proportional to the average European refrigerant charge to the average United States charge (i.e. 770/747 from the Vintaging model and Schwarz studies respectively). The newer vehicle emission rate is thus 18 g/yr for the average newer vehicle emissions (average for car and truck).

To derive the minimum score, the 18 gram per year rate was used as a ratio to convert the gram per mile emission impact into a new vehicle gram per year for the test. The car or truck direct a/c emission factor (gram per mile) was divided by the average emission factor (gram per mile) and then multiplied by the new vehicle average leakage rate (gram per year)

Equation 5-3 – J2727 Minimum Score

J2727 Minimum Score = Car or truck average pre control emissions (gram per mile)/ Fleet average pre-control emissions (grams per mile) x New vehicle annual leakage rate (grams per year) x Minimum Fraction

By applying this equation, the minimum J2727 score is fixed at 8.3 g/yr for cars and 10.4 g/yr for trucks. This corresponds to a total fleet average of 18 grams per year, with a maximum reduction fraction of 50%.

The GWP Refrigerant term in Equation 1 allows for the accounting of refrigerants with lower GWP (so that this term can be as low as zero in the equation), which is why the same minimum score is kept regardless of refrigerant used. It is technically feasible for the J2727 Minimum score to be less than the values presented in the table. But this will usually require the use of an electric compressor (see below for technology description).

5.1.2.3.2.3 AvgImpact Term

AvgImpact is the average annual impact of A/C leakage, which is 16.6 and 20.7 g/yr for cars and trucks respectively. This was derived using Equation 2, but by setting the minimum fraction to one.

5.1.2.3.2.4 GWPRefrigerant Term

This term is relates to the global warming potential (GWP) of the refrigerant as documented by EPA. A full discussion of GWP and its derivation is too lengthy for this space, but can be found in many EPA documents.[4c] This term is used to correct for refrigerants with global warming potentials that differ from HFC-134a.

5.1.2.3.2.5 HiLeakDisincentive

As proposed, EPA is adding (compared to the MYs 2012-2016 rule's formula) a disincentive to the leakage credit formula for systems which use a low GWP refrigerant, but "backslide" on low leakage levels. As stated above, low leakage levels provide an environmental benefit by maintaining the charge of the system. This has two advantageous effects. First, it preserves the efficiency of the system. Reduced refrigerant charge levels can reduce overall efficiency, especially if the compressor starts "short-cycling". Also, since lubrication is combined with most of the current and likely future refrigerants, the shortage of lubrication can wear out the compressor and cause it to seize and malfunction. CARB testing has shown that preserving the refrigerant charge level in a conventional A/C system results in improved system efficiency.[17] Second, by reducing the leak rate of the low GWP system, the probability that the new system will run out of charge will be minimized. When a system runs out of charge, vehicle owners can either drive without A/C, or have a professional recharge the system, or recharge the system themselves. The latter are called "do-it-yourself-ers" (DIYers). It is possible that DIYers (and some repair shops) may refill a low-GWP system (e.g., HFO-1234yf) with a high-GWP refrigerant (e.g., HFC-134a), in order to save on costs.[h] Due to the demand from the legacy fleet, refill containers of HFC-134a would be available to the market for many years to come (so it would be available to DIYers). Since the thermodynamic properties of HFC-134a and HFO-1234yf are similar, HFO-1234yf systems may function with HFC-134a, although with some reduced effectiveness, and in some systems may lead to long term damage.[i] Unfortunately, the extent to which this will occur is difficult to predict. EPA regulations prohibit topping-off a system with a refrigerant other than the original (for which the system was designed). EPA will use this disincentive credit to maintain low refrigerant leakage emission levels and to reduce the potential for leakage of high GWP refrigerants from systems that have been improperly recharged. Thus, EPA believes that there are real, but unquantifiable, benefits for a leakage disincentive credit, and we are finalizing a (Max)HiLeakDisincentive of 1.8 g/mi for cars and 2.1 g/mi for trucks. The EPA believes that these numbers strike a balance in that it is a large enough incentive to maintain low leakage levels, but it is not too large as to diminish incentive to switch to an alternative refrigerant.

The leakage rate at which a disincentive, or negative credit, would be generated (MinScore) was increased from the levels proposed in the NPRM. Most commenters requested that the EPA remove this negative credit for the final rule. Other commenters believed that the 8.3 g/yr and 10.4 g/yr thresholds for cars and trucks that we proposed were overly stringent, and that a more realistic value should be specified, based what the current fleet of vehicles is achieving. In response to these comments, we examined the approach we used in the MYs 2014-2018 rule for GHG Emissions Standards for Heavy-Duty Engines and Vehicles, where a maximum refrigerant leak rate standard of 11.0 g/year was set for vehicles with a refrigerant capacity of 733 g or less, and 1.5 percent of the system refrigerant capacity for vehicles with a refrigerant capacity greater than 733 g. We believe that the approach used in the heavy-duty GHG rule is appropriate for setting the threshold for which a HiLeakDisincentive (a "negative" credit) is generated in the MYs 2017-2025 light-duty GHG rule, as the air conditioning systems in both categories are similar, in terms of the components and materials used, as well as general system design and layout. Furthermore, analysis of the 2012 model year J2727-based leakage rate data in the State of Minnesota reporting database affirms that this approach will require leakage reductions in a large portion of the vehicle

[h] Refilling/ topping-off systems designed for use for one refrigerant (e.g., HFO-1234yf) with another refrigerant (e.g., HFC-134a) is a violation of CAA Section 612 regulations. See 40 CFR part 82, subpart G, appendix D, section 3.

[i] Based on discussions with vehicle manufacturers.

fleet, while allowing early adopters of low-leakage technologies to avoid the disincentive. In addition, this scaled approach, where larger A/C systems with higher refrigerant capacities can have a higher leakage rate before triggering the HiLeakDisincentive, provides manufacturers with the flexibility they need to install appropriately-sized A/C systems in larger vehicles, while using common low-leak technologies and components across their vehicle models. If a single threshold were applied to cars and trucks, extraordinary leakage mitigation measures would likely be necessary on larger systems in order to avoid the disincentive. Figure 5-1 illustrates how this approach to the HiLeakDisincentive fits within the 2012 model leakage scores for light-duty vehicles.

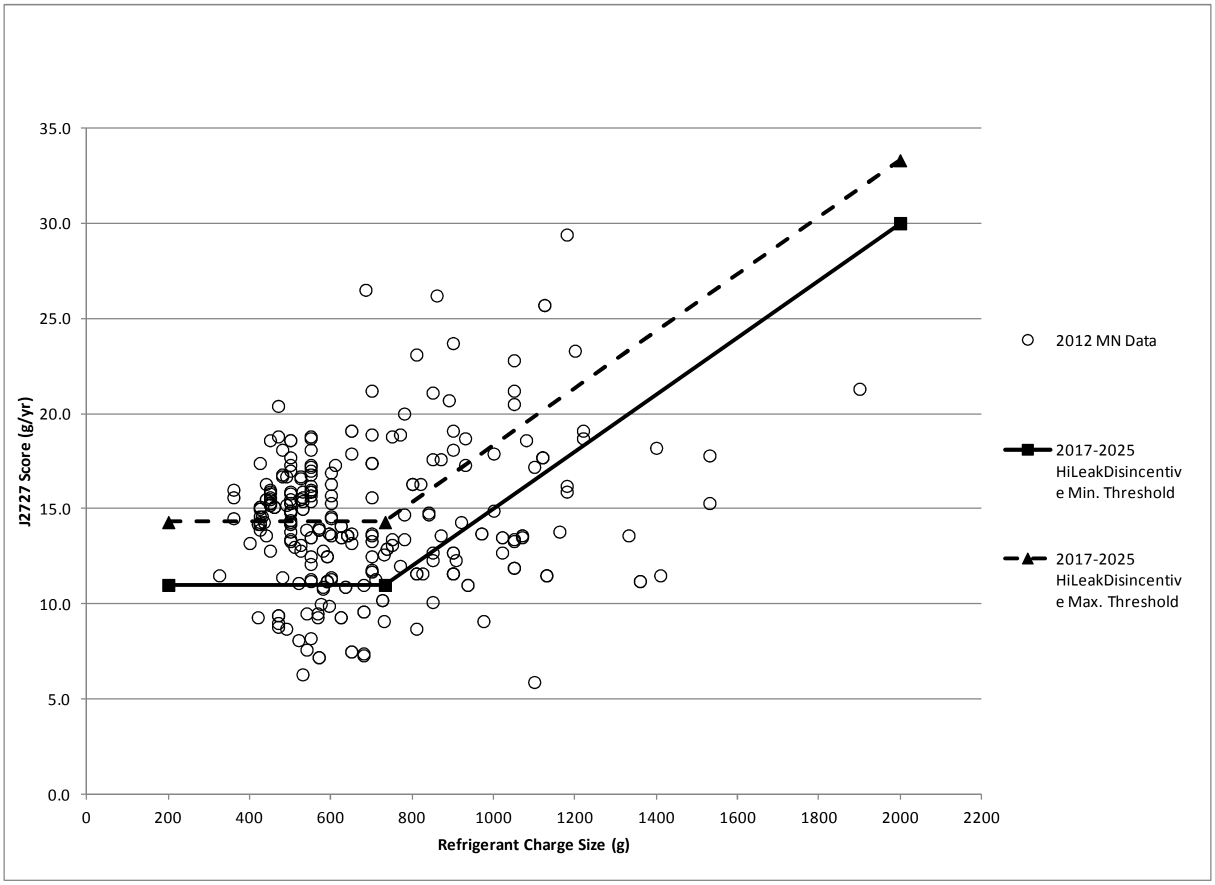


Figure 5-1 2012 State of Minnesota Leakage Reporting Data (All Vehicles) with HiLeakDis Thresholds

5.1.2.3.3 Why are the leakage credits different from the 2010 Technical Assessment Report?

The 2010 Technical Assessment report employed a different methodology for calculating the HFC credit, which resulted in significantly fewer credits available for A/C leakage compared to the MYs 2012-2016 final rule (approximately 40% less). The TAR analysis decreased the average charge size and leakage assumed in its analysis of future model years as compared to the MYs 2012-2016 final rule. In the present rule, we maintain the MYs 2012-2016 credit value. EPA chose this approach for both technical and policy reasons.

Like any inventory, the refrigerant inventory produced by the Vintaging model has uncertainties associated with it. This is especially true given that we do not know how many "high emitters" exist in the U.S. fleet. A high emitter is a vehicle that rapidly leaks HFC, but is also continually recharged. A typical light duty vehicle may require recharge approximately every seven years (see section 5.1.2.6). However, the owner of a high emitter may continually charge their systems each summer, thereby increasing the overall average emissions of the fleet. In the 2009-2010 study of the leakage rates from 70 in-use heavy duty vehicles, the California Air Resources Board found a relatively high prevalence of high emitting vehicles. Of the 70, 5 had leakage rates that were greater than one-half a charge per year, while seven additional vehicles had annualized leakage rates greater than one-quarter charge per year.[j] These values could potentially be used to recalculate the HFC inventories from the TAR and recalculate the leakage credit.

EPA considered the lower inventory discussed in the TAR as well as the CARB study when determining the leakage credit for this rule. While there is ultimately a mass balance between HFC produced and HFC leaked, this balance is not closed on an annual basis, and is difficult to directly verify. Given the counterbalancing factors, EPA made the policy decision to maintain continuity with the MYs 2012-2016 FRM analysis, and will incorporate this level of the credit in the standard setting process. A reduction in A/C credits (in 2017 compared to 2016 for example) would artificially increase the stringency of the standard for those manufacturers who generated leakage (and alternative refrigerant) credits in 2016 as a means of compliance. With little lead time, these manufacturers would need to add other technologies to their fleet in order to close the gap their compliance target created by a reduction in the maximum potential A/C credit. Alternately, the stringency of the 2017 standards would have to be relaxed, and in some cases may even be less stringent than 2016 standards if this adjustment is made.

ICCT expressed the concern that maintaining continuity with the earlier rule would encourage manufacturers to seek to generate leakage credits more aggressively than they otherwise would. As we stated above, we acknowledge that some manufacturers might choose a slightly different technology approach to compliance if fewer A/C leakage credits were available. However, we believe that the disruption to the transition from the MYs 2012-2016 rule to the MYs 2017-2025 rule that would result is not acceptable. Given the need for stability for the standards (and stringencies), EPA is "freezing" the credit assessment based on what we presented in the MYs 2012-2016 rule, and also presented again above.

5.1.2.4 Technologies That Reduce Refrigerant Leakage and their Effectiveness

In this section, the analysis used in the MYs 2012-2016 rule is again applied to the baseline technology levels and the effectiveness for leakage-reducing technologies. For the MYs 2012-2016 rule, EPA conducted an analysis to determine the historic leakage emission rate for motor vehicle A/C systems, and it was estimated in section 5.1.2.3.2.2 that the A/C systems in new vehicles would leak refrigerant at an average rate of 18 g/yr – a value which EPA believes represented the types of A/C components and technologies in use prior to MY

[j] While the Vintaging model assumes an average annualized leakage rate of 18% + 43% at end of life, it assumes that the MAC unit only lasts 12 years. Actual MACs, particularly those that are recharged, may last longer.

2007. EPA believes, through utilization of the leakage-reducing technologies described below, that it will be possible for manufacturers to reduce refrigerant leakage 50%, relative to the 18 g/yr baseline level.[18] EPA also believes that all of these leakage-reducing technologies are currently available, and that manufacturers will use these technologies to generate credits under provisions of the 2012-2016 rule, as well as under the provisions of this rule.

In describing the technologies below, only the relative effectiveness figures are presented, as the individual piece costs are not known. The EPA only has costs of complete systems based on the literature, and the individual technologies are described below.

5.1.2.4.1 Baseline Technologies

The baseline technologies assumed for A/C systems which have an average annual leak rate of 18 g/yr are common to many mass-produced vehicles in the United States. In these mass-produced vehicles, the need to maintain A/C system integrity (and the need to avoid the customer inconvenience of having their A/C system serviced due to loss of refrigerant) is often balanced against the cost of the individual A/C components. For manufacturers seeking improved system reliability, components and technologies which reduce leakage (and possibly increased cost) are selected, whereas other manufacturers may choose to emphasize lower system cost over reliability, and choose components or technologies prone to increased leakage. In EPA's baseline scenario, the following assumptions were made concerning the definition of a baseline A/C system:

- all flexible hose material is rubber, without leakage-reducing barriers or veneers, of approximately 650 mm in length for both the high and low pressure lines
- all system fittings and connections are sealed with a single o-rings
- the compressor shaft seal is a single-lip design
- one access port each on the high and low pressure lines
- two of the following components: pressure switch, pressure relief valves, or pressure transducer
- one thermostatic expansion valve (TXV)

The design assumptions of EPA baseline scenario are also similar to the sample worksheet included in SAE's surface vehicle standard J2727 – (R) HFC-134a Mobile Air Conditioning System Refrigerant Emission Chart.[10] In the J2727 emission chart, it is the baseline technologies which are assigned the highest leakage rates, and the inclusion of improved components and technologies in an A/C system will reduce this annual leakage rate, as a function of their effectiveness relative to the baseline. EPA considers these 'baseline' technologies to be representative of recent model year vehicles, which, on average, can experience a refrigerant loss of 18 g/yr. However, depending on the design of a particular vehicle's A/C system (e.g. materials, length of flexible hoses, number of fittings and adaptor plates, etc.), it is possible to achieve a leakage score much higher (i.e. worse) than 18 g/yr. According to manufacturer data submitted to the State of Minnesota, 19% of 2009 model year vehicles have a J2727 refrigerant score greater than 18 g/yr, with the highest-scoring vehicle reporting a leakage rate of 30.1 g/yr.[19] For the 2010 model year, the average J2727 leakage score reporting database was 14.0 g/yr for cars, and 14.8 g/yr for trucks, but this is simply the average result of all vehicles in the database, and does not reflect sales weighting of the leakage scores nor does it eliminate identical models (vehicles with different brands or nameplates, but identical with respect to the A/C system design and components) when calculating the average score.

Here again, the 18g/yr baseline is maintained at the MYs 2012-2016 rule levels for both technical and policy reasons. As mentioned earlier, there is great uncertainty in the leakage emissions from vehicles. The J2727 scoring system, which is calibrated to in-use emissions from properly functioning vehicles, does not include high emitters. EPA considers J2727 to be a surrogate for in-use emissions, and not necessarily an accurate representation of real-world emissions. Thus, to maintain continuity with MY 2016 standards (and credits), EPA is “freezing” the baseline assumption of leakage rate from the fleet.

5.1.2.4.2 Flexible Hoses

The flexible hoses on an automotive A/C system are needed to isolate the system from engine vibration and to allow for the engine to roll within its mounts as the vehicle accelerates and decelerates. Since the compressor is typically mounted to the engine, the lines going to-and-from the compressor (i.e. the suction and pressure lines) must be flexible, or unwanted vibration would be transferred to the body of the vehicle (or other components), and excessive strain on the lines would result. It has been industry practice for many years to manufacture these hoses from rubber, which is relatively inexpensive and durable. However, rubber hoses are not impermeable, and refrigerant gases will eventually migrate into the atmosphere. To reduce permeation, two alternative hose material can be specified. The first material, is known as a standard ‘veneer’ (or ‘barrier’) hose, where a polyamide (polymer) layer - which has lower permeability than rubber - is encased by a rubber hose. The barrier hose is similar to a veneer hose, except that an additional layer of rubber is added inside the polyamide layer, creating three-layer hose (rubber-polyamide-rubber). The second material is known as ‘ultra-low permeation’, and can be used in a veneer or barrier hose design. This ultra-low permeation hose is the most effective at reducing permeation, followed by the standard veneer or barrier hose. Permeation is most prevalent during high pressure conditions, thus it is even more important that these low permeable hoses are employed on the high pressure side, more so than on the low pressure side.

According to J2727, standard barrier veneer hoses have 25% the permeation rate of rubber hose, and ultra low permeable barrier veneer hoses have 10% the permeation rate (as compared to a standard baseline rubber hose of the same length and diameter). However, in the February 2012 version of J2727, manufacturers are required to use actual SAE J2064 hose permeation data, instead of the discrete values provided for various hose material and construction types, as was specified in previous versions of the J2727 method.

5.1.2.4.3 System Fittings and Connections

Within an automotive A/C system and the various components it contains (e.g. expansion valves, hoses, rigid lines, compressors, accumulators, heat exchangers, etc.), it is necessary that there be an interface, or connection, between these components. These interfaces may exist for design, manufacturing, assembly, or serviceability reasons, but all A/C systems have them to some degree, and each interface is a potential path for refrigerant leakage to the atmosphere. In SAE J2727 emission chart, these interfaces are described as fittings and connections, and each type of fitting or connection type is assigned an emission value based on its leakage potential; with a single O-ring (the baseline technology) having the highest leak potential; and a metal gasket having the lowest. In between these two extremes, a variety of sealing technologies, such as multiple o-rings, seal washers, and seal washers with o-rings, are available to manufacturers for the purpose of reducing leakage. It is expected that manufacturers will choose from among these sealing technology options to create an A/C system which offers the best cost-vs-leakage rate trade-off for their products.

The relative effectiveness of the fitting and connector technology is presented in Table 5-4. For example, the relative leakage factor of 125 for the baseline single O-ring is 125 times more "leaky" than the best technology - the metal gasket.

Table 5-4 Effectiveness of Fitting and Connector Technology

Fitting or Connector	Relative Leakage
Single O-ring	125
Single Captured O-ring	75
Multiple O-ring	50
Seal Washer	10
Seal Washer with O-ring	5
Metal Gasket	1
100% Helium Leak Test	10

5.1.2.4.4 Compressor Shaft Seal

A major source of refrigerant leakage in automotive A/C systems is the compressor shaft seal. This seal is needed to prevent pressurized refrigerant gasses from escaping the compressor housing. As the load on the A/C system increases, the pressure and the leakage past the seal also increase. In addition, with a belt-driven A/C compressor, a side load is placed on the compressor shaft by the belt, which can cause the shaft to deflect slightly. The compressor shaft seal must have adequate flexibility to compensate for this deflection, or movement, of the compressor shaft to ensure that the high-pressure refrigerant does not leak past the seal lip and into the atmosphere. When a compressor is static (not running), not only are the system pressures lower, the only side load on the compressor shaft is that from tension on the belt, and leakage past the compressor shaft is at a minimum. However, when the compressor is running, the system pressure is higher and the side load on the compressor shaft is higher (i.e. the side load is proportional to the power required to turn the compressor shaft) - both of which can increase refrigerant leakage past the compressor shaft seal. It is estimated that the rate of refrigerant leakage when a compressor is running can be 20 times that of a static condition.[20] Due to the higher leakage rate under running conditions, SAE J2727 assigns a higher level of impact to the compressor shaft seal. In the example shown in the August 2008 version of the J2727 document, the compressor is responsible for 58% of the system refrigerant leakage, and of that 58%, over half of that leakage is due to the shaft seal alone (the remainder comes from compressor housing and adaptor plate seals). To address refrigerant leakage past the compressor shaft, manufacturers can use multiple-lip seals in place of the single-lip seals.

5.1.2.5 Technical Feasibility of Leakage-Reducing Technologies

EPA believes that the leakage-reducing technologies discussed in the previous sections are available to manufacturers today, are relatively low in cost, and that their feasibility and effectiveness have been demonstrated by the SAE IMAC teams. EPA also believes – as has been demonstrated in the J2727 calculations submitted by manufacturers to the State of Minnesota – that reductions in leakage from 18 g/yr to 9 g/yr are possible (e.g. the 2009 Saturn Vue has a reported leakage score of 8.5 g/yr). In addition to generating credit for reduced refrigerant leakage, we expect many manufacturers to choose to introduce alternative refrigerant systems, such as HFO-1234yf, as discussed in Section III.C.1 of the preamble to this rule.

5.1.2.6 Deterioration in Leakage Controls

In the MYs 2012-2016 rule as well as in the proposal for this rule, EPA presented a "model" of the deterioration of leakage systems. This analysis would have been necessary if EPA wanted to quantify the maintenance benefits of leakage control. EPA received no comments on this model for the proposal. For this final rule, EPA is not claiming maintenance cost savings due to refrigerant leakage regulations. This is due to uncertainty as to how these low-leak technologies will actually perform and deteriorate in use. While we expect that low-leak systems will have a lower probability of a requiring a recharge maintenance event, or at least a longer period before such an event is required, it is difficult to quantify such factors, and such quantification is necessary for their inclusion in a cost-benefit analysis. Moreover, EPA is estimating that the predominant technology in the MYs 2017-2025 timeframe will be alternative refrigerants[k], thus minimizing the need for this deterioration model.

Despite the fact that we are not using the deterioration model (as proposed), EPA believes that it is important to address the issue as it relates to the hi-leak disincentive. Since the deterioration model was presented, EPA has reconsidered some of the assumptions that went into the model. Given that the deterioration mechanisms are not fully understood and quantified, it is difficult to project the precise rate at which leak-reducing A/C technologies will deteriorate compared to conventional technologies. But we do know that even if a similar rate of deterioration is assumed, the A/C system with a lower initial leakage rate will have a lower frequency of required recharge events over its lifetime, as it will take the low-leak vehicle longer to reach a level of 50 percent charge remaining in the system. In addition, we believe that many of the leak-reducing technologies, such as use of seal washers in place of O-rings, and 100 percent leak testing of assembled components with helium, are inherently beneficial to system durability. In the case of seal washers, a rigid, metal connection is created at system joints instead of a less-rigid o-ring seal, which can be susceptible to damage upon installation. In the case of helium leak testing, any defective joints, connections, or components are detected prior to installation in the vehicle, which reduces the probability of

[k] Though we are encouraging manufacturers to keep the leakage scores low with the hi leak disincentive.

vehicles with higher-than-expected leakage leaving the assembly plant. EPA believes that establishing an incentive to achieve low-leak systems through a HiLeakDisincentive (see 5.1.2.3.2.5) will result in lower deterioration rates and extend the interval for which a system recharge is required. For these reasons, EPA believes that the deterioration model presented in the proposal was potentially overly “conservative”. EPA will continue to monitor data in the future on the issue of leakage deterioration and the effects of the hi-leak disincentive.

5.1.2.7 Other Benefits of Improving A/C Leakage Performance

The EPA is assuming that a reduction in leakage emissions from new vehicles will also improve the leakage over the lifetime of the vehicle. There is ample evidence to show that A/C systems that leak more also have other problems that occur (especially with the compressor) due to the lack of oil circulating in the system. Thus, it is expected that an A/C system which utilizes leak-reducing components and technologies should, on average, last longer than one which does not.

A European study conducted in 2001 (by Schwarz) found that the condenser is the component most likely to fail and result in a total leak.[21] The study also found that compressor component was most likely the culprit when other malfunctions were present (other than total loss). A more recent (and larger) study found that condensers required replacement at half the rate of a compressor (10% vs 19% of the entire part replacement rate), and that evaporators and accumulators failed more often.[16] The same study also found that many of the repairs occurred when the vehicles were aged 5-10 years. Both these studies indicate that the condenser and compressor are among the major causes of failure in an A/C system. Leakage reductions in the system are expected to greatly reduce the incidence of compressor repair, since one of the main root causes of compressor failure is a shortage of lubricating oil, which originates from a shortage of refrigerant flowing through the system (and it is a refrigerant-oil mixture which carries lubricating oil to the compressor).[22]

Monitoring of refrigerant volume throughout the life of the A/C system may provide an opportunity to circumvent some previously described failures specifically related to refrigerant loss. Similar to approaches used today by the engine on-board diagnostic systems (OBD) to monitor engine emissions, a monitoring system that informed the vehicle operator of a low refrigerant level could potentially result in significant reductions in A/C refrigerant emissions due to component failure(s) by creating an opportunity for early repair actions. While most A/C systems contain sensors capable of detecting the low refrigerant pressures which result from significant refrigerant loss, these systems are generally not designed to inform the vehicle operator of the refrigerant loss, and that further operation of the unrepaired system can result in additional component damage (e.g. compressor failure). Electronic monitoring of the refrigerant may be achieved by using a combination of existing A/C system sensors and new software designed to detect refrigerant loss before it progresses to a level where component failure is likely to occur.

EPA requested comment in the 2012-2016 NPRM on allowing additional leakage credits for systems that monitor the leak levels, especially where manufacturers are willing to warrant such systems. Presently, the EPA is not aware if any such technology exists to accurately monitor refrigerant levels, as the technical challenges are high. As a result, there were no manufacturers who expressed interest in this credit, and the EPA did not finalize such credits in the 2012-2016 program. EPA again sought comment during the MY 2017-2025 proposal on allowing these credits again, in the hopes of encouraging innovative technologies to monitor leakage levels. ICCT supported EPA request for monitoring technology in their comments, however, no manufacturer (or supplier) provided comment on this issue and EPA remains unaware of any such technology in existence (much less in implementation).

5.1.3 CO_2 Emissions and Fuel Consumption due to Air Conditioners

As stated above, for model years 2012 to 2016, EPA provided credits for the use of A/C technologies that improve efficiency and achieve reductions in indirect CO_2 emissions related to A/C use. These credits were not previously applicable to the CAFE program fuel economy calculations. For this rule, the agencies are finalizing provisions that the A/C indirect credits are applicable to both the greenhouse gas and fuel economy calculations.

5.1.3.1 Impact of Air Conditioning Use on Fuel Consumption and CO_2 Emissions

Three studies have been performed in recent years which estimate the impact of A/C use on the fuel consumption of motor vehicles in the United States. In the first study, the National Renewable Energy Laboratory (NREL) and the Office of Atmospheric Programs (OAP) within EPA have performed a series of A/C related fuel use studies.[23,24] The energy needed to operate the A/C compressor under a range of load and ambient conditions was based on testing performed by Delphi, an A/C system supplier. They used a vehicle simulation model, ADVISOR, to convert these loads to fuel use over the EPA's FTP test cycle. They developed a personal "thermal comfort"-based model to predict the percentage of drivers which will turn on their A/C systems under various ambient conditions. Overall, NREL estimated A/C use to represent 5.5% of car and light truck fuel consumption in the U.S.

In the second study, the California Air Resources Board (CARB) estimated the impact of A/C use on fuel consumption as part of their GHG emission rulemaking.[25] The primary technical analysis utilized by ARB is summarized in a report published by NESCCAF for CARB. The bulk of the technical work was performed by two contractors: AVL Powertrain Engineering and Meszler Engineering Services. This work is founded on that performed by NREL-OAP. Meszler used the same Delphi testing to estimate the load of the A/C compressor at typical ambient conditions. The impact of this load on onroad fuel consumption was estimated using a vehicle simulation model developed by AVL - the CRUISE model - which is more sophisticated than ADVISOR. These estimates were made for both the EPA FTP and HFET test cycles. (This is the combination of test cycle results used to determine compliance with NHTSA's current CAFE standards.) NREL's thermal comfort model was used to predict A/C system use in various states and seasons.

The NESCCAF results were taken from Table 3-1 of their report and are summarized in Table 5-5.[26]

Table 5-5 CO_2 Emissions Over 55/45 FTP/HFET Tests and From A/C Use (g/mi) Based on the NESCCAF study

	Small Car	Large Car	Minivan	Small Truck	Large Truck
55/45 FTP/HFET	278	329	376	426	493
Indirect A/C Fuel Use (g/mi CO_2)	16.8	19.1	23.5	23.5	23.5
Total	294.8	348.1	399.5	449.5	516.5
Indirect A/C Fuel Use	5.7%	5.5%	5.9%	5.2%	4.6%

NESCCAF estimated that nationwide, the average impact of A/C use on vehicle fuel consumption ranged from 4.6% for a large truck or SUV, to 5.9% for a minivan. The impact on vehicle CO_2 and fuel consumption resulting from A/C use was determined using a 55%/45% weighting of CO_2 emissions from EPA FTP and HFET tests (hereafter referred to simply as FTP/HFET). Simulation modeling to assess A/C related fuel consumption and CO_2 emissions was first conducted without the load from the A/C system followed by modeling which included the load from the A/C system. For the purposes of this analysis of A/C system fuel use, the percentage of CO_2 emissions and fuel use are equivalent, since the type of fuel being used is always gasoline.[1]

In the MYs 2012-2016 rule, there was a third analysis presented along with a thorough comparison of these studies. While not repeated here, it was estimated that the impact of A/C on onroad fuel consumption was 3.9% based on a combination of the results from these studies. This resulted in an average impact of 14.3g/mi (independent of car or truck type) and hence a maximum of 5.7 g/mi credit, identical for car and truck (based on a 40% improvement feasibility). For this rule, EPA has conducted a new analysis, which supports the results achieved in the MYs 2012-2016 final rule, though there is now a distinction made between cars and trucks as it relates to A/C efficiency impacts (and credits).

5.1.3.2 Updated Analysis of Efficiency Impacts

As just mentioned, in the Light-Duty GHG final rule for model years 2012 through 2016, EPA estimated that the average CO_2 emission increase due to A/C use would be 14.3 g/mi taking into account both manual and automatic climate control systems with market penetrations of 62% and 38%, respectively. For this study of the A/C compressor load impact on vehicle fuel economy, EPA relied on comparisons of measured fuel economy over two warmed up bags (or phases) of the FTP test (without A/C operating) and the SC03 test (A/C emissions test). EPA had based its estimates on testing of over 600 production vehicles. These test results were combined with the Phoenix study, where the A/C compressor on-time was estimated to be 23.9% for manual climate control systems and 35% for automatic climate control systems. For more technical details, one can refer to the Regulatory Impact Analysis for the model year 2012 to 2016 final rule.

[1] Because NESCCAF estimated A/C fuel use nationwide, while ARB focused on that in California, the NESCCAF and EPA methodologies and results are compared below.

For the proposed and final rule, EPA developed a more robust and systematic method of estimating vehicle CO_2 emissions related to A/C usage. This method is based on a sophisticated, newly-developed EPA vehicle simulation tool. The next few paragraphs provide an overview of the vehicle simulation tool and describe how this approach improves on the earlier analysis. More detailed descriptions about the vehicle simulation tool and its use for the A/C indirect impact analysis are in Chapter 2 of the EPA Regulatory Impact Analysis.

Over the past year, EPA has developed full vehicle simulation capabilities in order to support regulations and vehicle compliance by quantifying the effectiveness of different technologies with scientific rigor over a wide range of engine and vehicle operating conditions. This in-house simulation tool has been developed for modeling a wide variety of light, medium, and heavy duty vehicle applications over various driving cycles. In order to ensure transparency of the models and free public access, EPA has developed the tool in MATLAB/Simulink environment with the completely open source code. To support these simulation capabilities in part, EPA is upgrading its testing infrastructure (such as engine test cells, vehicle dynamometers, Portable Emissions Measurement Systems, and a battery laboratory) at the National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan. This testing infrastructure provides necessary data to calibrate and validate vehicle simulations, such as engine fuel maps, engine torque maps, vehicle aerodynamic parameters, battery, electrical component parameters, etc.

EPA's first application of the vehicle simulation tool was for purposes of heavy-duty vehicle compliance and certification. For the model years 2014 to 2018 final rule for medium and heavy duty trucks, EPA created the "Greenhouse gas Emissions Model" (GEM), which is used both to assess Class 2b-8 vocational vehicle and Class 7/8 combination tractor GHG emissions and fuel efficiency and to demonstrate compliance with the vocational vehicle and combination tractor standards. See 40 CFR sections 1037.520 and 1037.810. This GEM documentation is also currently in publication.[27]

For light-duty vehicles, EPA has developed a conventional (non-hybrid) vehicle simulation tool and used it to estimate indirect A/C CO_2 emissions. These estimates are used, in turn, to quantify the maximum amount of indirect A/C credit (i.e. the maximum credit potential). As mentioned previously, the tool is based on MATLAB/Simulink and is a forward-looking full vehicle model that uses the same physical principles as other commercially available vehicle simulation tools (e.g. Autonomie, AVL-CRUISE, GT-Drive, etc.) to derive the governing equations. These governing equations describe steady-state and transient behaviors of each electrical, engine, transmission, driveline, and vehicle systems, and they are integrated together to provide overall system behavior during transient conditions as well as steady-state operations. Chapter 2 of EPA's Regulatory Impact Analysis provides more details on this light-duty vehicle simulation tool used for estimating indirect A/C impact on fuel consumption.

In the light-duty vehicle simulation tool, there are four key system elements that describe the overall vehicle dynamics behavior and the corresponding fuel efficiency: electrical, engine, transmission, and vehicle. The electrical system model consists of parasitic electrical load and A/C blower fan, both of which were assumed to be constant. The engine system model is comprised of engine torque and fueling maps. For estimating indirect A/C impact on fuel consumption increase, two engine maps were used: baseline and EGR boost engines. These engine maps were obtained by reverse-engineering the vehicle simulation results provided by Ricardo Inc. For the transmission system, a Dual-Clutch Transmission (DCT) model was created and used along with the gear ratios and shifting schedules used for the earlier Ricardo simulation work. For the vehicle system, four vehicles were modeled: small, mid, large size passenger vehicles, and a light-duty pick-up truck. The transient behavior and thermodynamic properties of the A/C system was not explicitly simulated, in favor of a simpler approach of capturing the compressor load based on national average ambient conditions. We believe this simplification is justified since the goal is to capture the behavior on the average of a fleet of vehicles (not the behavior of an individual make or model).

In order to properly represent average load values to the engine caused by various A/C compressors and vehicle types, EPA has adopted power consumption curves of A/C systems, published by an A/C equipment supplier, Delphi.[28,29] Also, in an effort to characterize an average A/C compressor load in the presence of widely varying environmental conditions in the United States, EPA has adopted data from the National Renewable Energy Laboratory (NREL) to estimate environmental conditions associated with typical vehicle A/C usage.[30,31,32] Based on the NREL data, EPA selected an A/C power consumption curve as a function of engine speed that was acquired by Delphi at 27°C and 60% relative humidity as a representative average condition. This power consumption curve data was taken from a fixed displacement compressor with a displacement volume of 210 cc. Thus, the curve includes the effect of compressor cycling as well as non-summer defrost/defog usage. In order to associate each vehicle type with the appropriate A/C compressor displacement, EPA scaled the curve based on the displacement volume ratio. For determining indirect A/C impact on fuel consumption increase, EPA estimated A/C compressor sizes of 120 cc, 140 cc, 160 cc, and 190 cc for small, medium, large passenger vehicles, and light-duty pick-up truck, respectively. By applying the displacement volume ratios to the 210 cc power consumption curve, EPA created A/C load curves for four vehicle types, as shown in Figure 5-2.

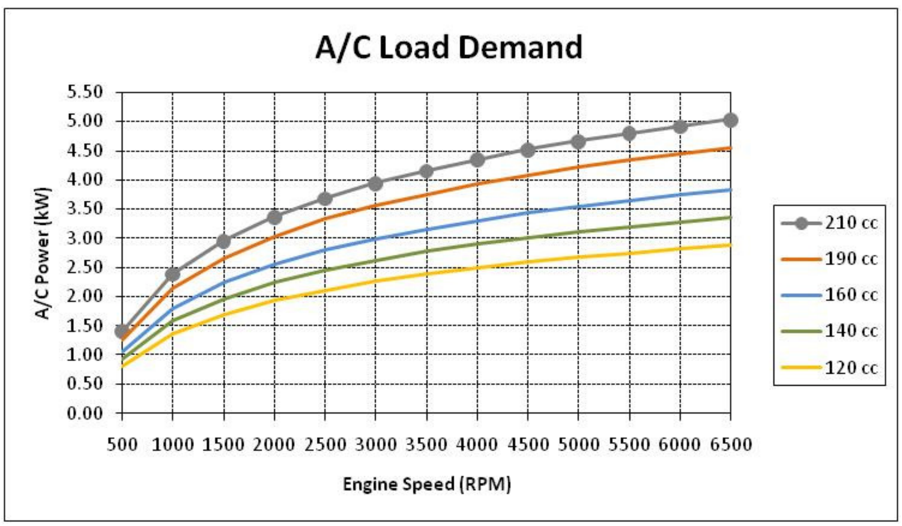


Figure 5-2 Representative A/C Compressor Load Curves

With these A/C compressor load curves, EPA ran full vehicle simulations based on the following matrix. In this matrix, the baseline engine represents a typical Spark-Ignition (SI), Port-Fuel Injection (PFI), Naturally-Aspirated (NA) engine equipped with a Variable Value Actuation (VVA) technology. In this technology, the valve timing (both intake and exhaust) is continuously varied over a wide range of engine operating conditions in order to result in optimal engine breathing efficiency. On the other hand, the EGR boost engine uses turbocharging and cooled EGR to increase engine's Brake Mean Effective Pressure (BMEP) level while managing combustion and exhaust temperatures. This engine usually has a peak BMEP of 25 to 30 bar, which supports significant downsizing (e.g. about 50%) compared to the baseline engines. Table 5-6 provides simulation results over SC03 driving cycle with an EGR boost engine for various vehicle classes.

- Small, medium, large cars, and pick-up truck
- FTP, Highway, and SC03 cycles
- Baseline and EGR boost engines
- A/C off and A/C on

Table 5-6 Vehicle Simulation Results on CO_2 Emissions over SC03 Cycle with EGR Boost Engine

SC03 Cycle		Small Car	Medium Car	Large Car	Truck
CO_2 with A/C off	[g/mi]	196.4	235.7	293.7	472.4
CO_2 Increase with A/C on	[g/mi]	11.7	12.0	13.8	17.2
Total CO_2 with A/C	[g/mi]	208.1	247.7	307.5	489.6
Indirect A/C Fuel Use	[%]	5.6	4.8	4.5	3.5

EPA ran the SC03 cycle simulations instead of FTP/Highway combined cycle simulations so that the simulation results would represent the actual A/C cycle test. EPA also assumed the EGR boost engine during vehicle simulations because EGR boost engine better represents engine technology more likely to be implemented in model years 2017 to 2025 and because the A/C impact on CO_2 increase in the EGR boost engine is similar to that in the baseline engine as shown in Table 5-6 and Table 5-7. Details of this analysis which showed impact of A/C usage on fuel consumption is independent of engine technology are provided in the next section. Moreover, EPA assumed 38% of a market penetration for automatic climate control systems as well as 23.9% and 35.0% of A/C on-time for manual and automatic climate control systems, respectively. These are the same assumptions made in the MYs 2012-2016 rule.[33] In order to come up with overall impact of A/C usage on CO_2 emissions for passenger cars, the simulation results for cars shown in Table 5-6 were sales-weighted for each model year from 2017 to 2025. For the end result, the impact of A/C usage was estimated at 11.9 CO_2 g/mile for cars and 17.2 CO_2 g/mile for trucks. This corresponds to an impact of approximately 14.0 CO_2 g/mile for the (2012) fleet, which is comparable to the MYs 2012-2016 final rule result, but still lower than the two studies by NREL and NESCCAF cited above.

5.1.3.2.1 Effect of Engine Technology on Fuel Consumption by A/C System

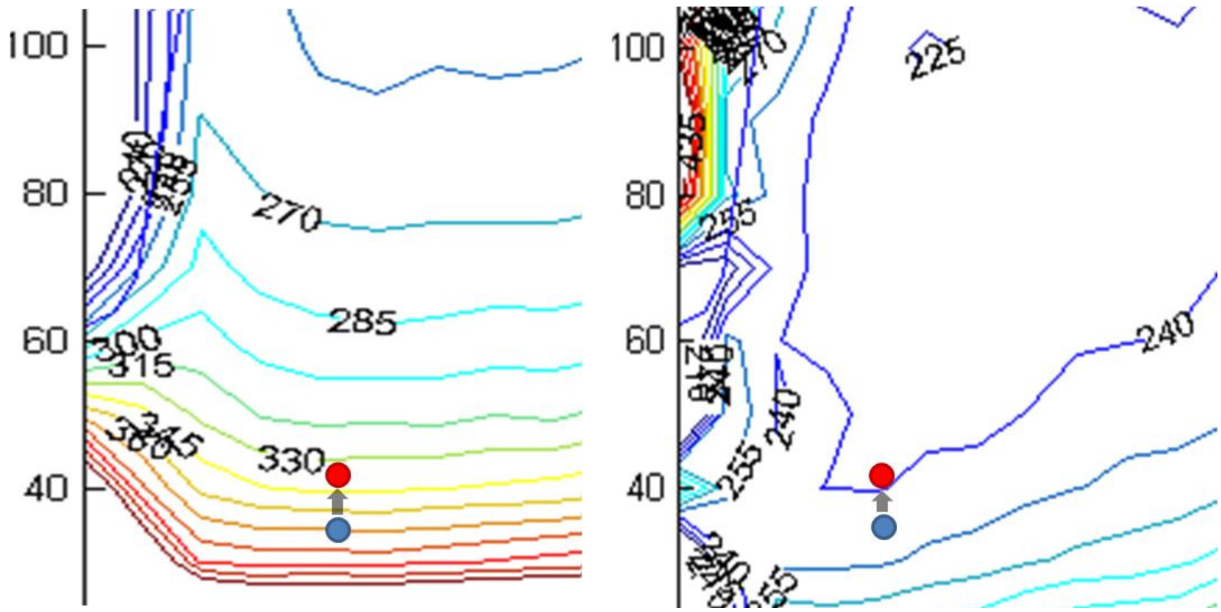
In order to continue to maintain the credit levels from the MYs2012-2016 rule, EPA had to first demonstrate that the fuel economy and CO_2 emissions due to A/C was relatively insensitive to the engine technologies that may be expected to be prevalent in the future. If for example, more efficient engines are able to run the A/C system more efficiently such that the incremental increase in emissions due to A/C decreased compared to the base engines, then credits for the same A/C technologies must decrease over time as engines become more efficient. This would correspond to a decrease in credits proportional (or multiplicative) to the increase in efficiency of the engine. Conversely, if the incremental increase in emissions due to A/C remained relatively constant, then the credits available for A/C efficiency should also remain stable. This would correspond to the credits (A/C impact) being additive to the base emissions rate, thus being independent of engine efficiency). The EPA based the hypothesis on the latter assumption.

In order to prove out this hypothesis, EPA carried out vehicle simulations for several cases, including two engine technologies: baseline and EGR boost engines (a surrogate for a future advanced efficient engine). Table 5-7 shows the vehicle simulation results of CO_2 emissions over the SC03 driving cycle when baseline engines are used, as opposed to the advanced EGR boost engines. By comparing the values of CO_2 increase with A/C on in Table 5-6 and Table 5-7, it is evident that the impact of A/C usage on fuel consumption is not very dependent on the engine technologies. In fact, the difference in the CO_2 increase with A/C on (2^{nd} row in table) between the emissions from the baseline and EGR boost engines is less than 10% for all vehicle classes.

Table 5-7 Vehicle Simulation Results on CO_2 Emissions over SC03 Cycle with Baseline Engine

SC03 Cycle		Small Car	Medium Car	Large Car	Truck
CO_2 with A/C off	[g/mi]	259.3	348.0	425.4	628.1
CO_2 Increase with A/C on	[g/mi]	11.3	11.1	12.5	16.2
Total CO_2 with A/C	[g/mi]	270.6	359.1	437.9	644.3
Indirect A/C Fuel Use	[%]	4.2	3.1	2.9	2.5

Figure 5-3 depicts zoomed-in BSFC maps for baseline and EGR boost engines. The circles on these maps represent average operating conditions of the engines over the FTP (city) drive cycle. The blue circle represents a simulated average operating condition without A/C while the red circle represents an average operating condition with A/C. As can be seen in the figure, the engines operate at higher load levels when the A/C is on. In this figure, the x and y axes present engine speed in RPM and torque in Nm, respectively.



(a) Baseline Engine (b) EGR Boost Engine

Figure 5-3 Average Engine Operating Conditions with A/C Off and A/C On over Fueling Maps for Baseline and EGR Boost Engines

For the baseline engine case, the engine efficiency improves significantly (375 g/kW-h to almost 330 g/kW-h) as it moves along the BSFC surface, whereas the improvement is much less for the EGR boost engine as it moves from approximately 250 g/kW-h to 240 g/kW-h. However, the large improvement in AC efficiency for the baseline engine is offset by the fact that the engine itself is less efficient than the EGR boost engine. Conversely, the small AC efficiency improvement for the EGR boost engine is compensated by the fact that the engine is much more efficient than the baseline engine. As a result, the CO_2 increase seen by both engines due to A/C usage becomes similar between the two different technologies. This result allows us to approximate the A/C impact on vehicle fuel consumption as an additive effect rather than as a multiplicative effect since it is independent of engine technologies. For the same reason, it also means that A/C credits for a given technology can remain constant over time, which will greatly simplify the progression of future credits.[m]

5.1.3.3 Technologies That Improve Efficiency of Air Conditioning and Their Effectiveness

Most of the excess load on the engine comes from the compressor, which pumps the refrigerant around the system loop. Significant additional load on the engine may also come from electrical or hydraulic fan units used for heat exchange across the condenser and

[m] It also means that the last row in the above two tables are a bit misleading as A/C impact should not be quantified as a fraction of the total emissions, but rather an additive increment. The numbers are left onto the tables for comparison purposes to studies in the literature that use this convention.

radiator. The controls that EPA and NHTSA believe manufacturers would use to generate credits for improved A/C efficiency and to improve fuel efficiency in the CAFE program through the use of an adjustment in calculated fuel economy would focus primarily, but not exclusively, on the compressor, electric motor controls, and system controls which reduce load on the A/C system (e.g. reduced 'reheat' of the cooled air and increased of use recirculated cabin air). EPA and NHTSA are finalizing a program that will result in improved efficiency of the A/C system (without sacrificing passenger comfort) while improving the fuel efficiency of, and reducing the CO_2 emissions from, the vehicle.

The cooperative IMAC program described above has demonstrated that average A/C efficiency can be improved by 36.4% (compared to an average MY 2008 baseline A/C system), when utilizing "best-of-best" technologies.[34] EPA and NHTSA consider a baseline A/C system to contain the following components and technologies; internally-controlled fixed displacement compressor (in which the compressor clutch is controlled based on 'internal' system parameters, such as head pressure, suction pressure, and/or evaporator outlet temperature); blower and fan motor controls which create waste heat (energy) when running at lower speeds; thermostatic expansion valves; standard efficiency evaporators and condensers; and systems which circulate compressor oil throughout the A/C system. These baseline systems are also extraordinarily wasteful in their energy consumption because they add heat to the cooled air out of the evaporator in order to control the temperature inside the passenger compartment. Moreover, many systems default to a fresh air setting, which brings hot outside air into the cabin, rather than recirculating the already-cooled air within the cabin.

The IMAC program indicates that improvements can be accomplished by a number of methods related only to the A/C system components and their controls including: improved component efficiency, improved refrigerant cycle controls, and reduced reheat of the cooled air. The program EPA and NHTSA are finalizing will encourage the reduction of A/C CO_2 emissions from cars and trucks by up to 42% from current baseline levels through a CO2 credit and fuel economy improvement system. EPA and NHTSA believe that the component efficiency improvements demonstrated in the IMAC program, combined with improvements in the control of the supporting mechanical and electrical devices (i.e. engine speeds and electrical heat exchanger fans), can go beyond the IMAC levels and achieve a total efficiency improvement of 42% through incremental improvements beyond that shown in the study due to the long lead time before MY 2017. The following sections describe the technologies the agencies believe manufacturers can use to attain these efficiency improvements.

Based on the new vehicle simulation research conducted by the EPA described above, the EPA believes that the impact of A/C on average CO_2 emissions amounts to 11.9 CO_2 g/mile for cars and 17.2 CO_2 g/mile for trucks (0.001339/0.001935 gallons of gasoline per mile car/truck improvement) and that these results are relatively insensitive to the engine and transmission efficiency improvements expected to be seen during the rule timeframe. A 42% improvement on this emissions rate leads to the maximum credit opportunity of 5.0 g CO2/mi for cars and 7.2 g CO2/mi for trucks (-0.000563 / -0.000810 gallons per mile car/truck improvement). This compares to the 5.7 g/mi (identical for cars and trucks) finalized in the 2012-2016 final rule. When cars and trucks are combined, the new final rule maximum credits are consistent (on a fleet level) with those finalized in the previous rule, though for cars the credits are now somewhat reduced and for trucks increased. The agencies believe that the modification of these credits for this rule is justified given the simulation work conducted, which shows that A/C emissions tends to be larger for the larger vehicles (and trucks tend to be larger than passenger cars).

The following sections discuss each of the A/C efficiency-improving technologies that EPA recognizes in the efficiency credit menu. We estimated the effectiveness of each of these technologies for the MYs 2012-2017 rule based on a variety of sources, including testing under the IMAC program and internal EPA testing. We did not receive comments challenging these estimates and continue to base the efficiency credits (and CAFE improvement values) on these estimates.

5.1.3.3.1 Reduced Reheat Using a Externally-Controlled, Variable-Displacement Compressor

The term 'external control' of a variable-displacement compressor is defined as a mechanism or control strategy where the displacement of the compressor adjusted electronically, based on the temperature setpoint and/or cooling demand of the A/C system control settings inside the passenger compartment. External controls differ from 'internal controls' that internal controls adjust the displacement of the compressor based on conditions within the A/C system, such has head pressure, suction pressure, or evaporator outlet temperature. By controlling the displacement of the compressor by external means, the compressor load can be matched to the cooling demand of the cabin. With internal controls, the amount of cooling delivered by the system may be greater than desired, at which point the cooled cabin air is then 'reheated' to achieve the desired cabin comfort. It is this reheating of the air which results reduces the efficiency of the A/C system – compressor power is consumed to cool air to a temperature less than what is desired.

Reducing reheat through external control of the compressor is a very effective strategy for improving A/C system efficiency. The SAE IMAC team determined that an annual efficiency improvement of 24.1% was possible using this technology alone.[34] The agencies estimate that additional improvements to this technology are possible (e.g. the increased use of recirculated cabin air), and that when A/C control systems and components are fully developed, calibrated, and optimized to particular vehicle's cooling needs, an efficiency improvement of 42% can be achieved, compared to the baseline system.

5.1.3.3.2 Reduced Reheat Using a Externally-Controlled, Fixed-Displacement or Pneumatic Variable-Displacement Compressor

When using a fixed-displacement or pneumatic variable-displacement compressor (which controls the stroke, or displacement, of the compressor based on system suction pressure), reduced reheat can be realized by disengaging the compressor clutch momentarily to achieve the desired evaporator air temperature. This disengaging, or cycling, of the compressor clutch must be externally-controlled in a manner similar to that described in 2.3.2.1. The agencies believe that a reduced reheat strategy for fixed-displacement and pneumatic variable-displacement compressors can result in an efficiency improvement of 20%. This lower efficiency improvement estimate (compared to an externally-controlled variable displacement compressor) is due to the thermal and kinetic energy losses resulting from cycling a compressor clutch off-and-on repeatedly.

5.1.3.3.3 Defaulting to Recirculated Cabin Air

In ambient conditions where air temperature outside the vehicle is much higher than the air inside the passenger compartment, most A/C systems draw air from outside the vehicle and cool it to the desired comfort level inside the vehicle. This approach wastes energy because the system is continuously cooling the hotter outside air instead of having the A/C system draw its supply air from the cooler air inside the vehicle (also known as recirculated air, or 'recirc'). By only cooling this inside air (i.e. air that has been previously cooled by the A/C system), less energy is required, and A/C Idle Tests conducted by EPA indicate that an efficiency improvement of 35-to-40% improvement is possible under idle conditions. Ongoing testing on the new AC17 test, described below, may in the future shed light on the overall effectiveness of this technology during other driving conditions.

A mechanically-controlled door on the A/C system's air intake typically controls whether outside air, inside air, or a mixture of both, is drawn into the system. Since the typical 'default' position of this air intake door is outside air (except in cases where maximum cooling capacity is required, in which case, many systems automatically switch this door to the recirculated air position), EPA and NHTSA are specifying that, as cabin comfort and de-fogging conditions allow, an efficiency credit be granted if a manufacturer defaults to recirculated air whenever the outside ambient temperature is greater than 75°F. To maintain the desired quality inside the cabin (in terms of freshness and humidity), EPA believes some manufacturers will control the air supply in a 'closed-loop' manner, equipping their A/C systems with humidity sensors or fog sensors (which detect condensation on the inside glass), allowing them to adjust the blend of fresh-to-recirculated air and optimize the controls for maximum efficiency. Vehicles with closed-loop control of the air supply (i.e. sensor feedback is used to control the interior air quality) will qualify for a 1.7 g/mi CO_2 credit and a 0.000124 gal/mi fuel consumption improvement. Vehicles with open-loop control (where sensor feedback is not used to control interior air quality) will qualify for a 1.1 g/mi CO_2 credit and a 0.000124 gal/mi fuel consumption improvement. We believe that the closed-loop control system will be inherently more efficient than the open-loop control system because the former can maximize the amount to recirculation to achieve a desired air quality and interior humidity level, whereas the latter will use a fixed 'default' amount of recirculated air which provides the desired air quality under worst case conditions (e.g. maximum number of passengers in the vehicle).

Electric drive vehicles such as HEVs, PHEVs and EVs may require some fraction of the A/C cooling capacity to control the battery temperature under hot conditions. PHEVs are most likely to require A/C cooling because their batteries have higher current requirements for all-electric driving than HEVs, and much less battery mass and energy storage than pure EVs. Some electrified vehicles today, such as the Nissan Leaf, cool their batteries with outside air, while others, such as the Toyota Prius and Ford Fusion Hybrid, use cooled cabin air, and the Chevrolet Volt is an example of a vehicle which uses a refrigerant loop to cool the battery coolant and thus to cool the battery. With the increased penetration of these electrified vehicles, it is possible that there will be some loss of efficiency of the A/C system (especially as it relates to cabin air recirculation). Vehicles which use cabin air to cool the battery must discharge this heated air outside the vehicle, rather than recirculating it through the climate control system. Currently, EPA does not account for this A/C efficiency loss in the credit menu. EPA and NHTSA requested comments on the technical merits or applicability of accounting for this loss of efficiency within the crediting and fuel economy improvement scheme, however there were no comments submitted. The agencies are therefore not making any adjustment in the credit menu for electric drive vehicles. As these types of vehicles become more common, the agencies will continue to study the effectiveness of air conditioning technologies.

5.1.3.3.4 Improved Blower and Fan Motor Controls

In controlling the speed of the direct current (DC) electric motors in an air conditioning system, manufacturers often utilize resistive elements to reduce the voltage supplied to the motor, which in turn reduces its speed. In reducing the voltage however, these resistive elements produce heat, which is typically dissipated into the air ducts of the A/C system. Not only does this waste heat consume electrical energy, it contributes to the heat load on the A/C system. One method for controlling DC voltage is to use a pulsewidth modulated (PWM) controller on the motor. A PWM controller can reduce the amount of energy wasted, and based on Delphi estimates of power consumption for these devices, EPA and NHTSA believe that when more efficient speed controls are applied to either the blower or fan motors, an overall improvement in A/C system efficiency of 15% is possible.[35]

5.1.3.3.5 Internal Heat Exchanger

An internal heat exchanger (IHX), which is alternatively described as a suction line heat exchanger, transfers heat from the high pressure liquid entering the evaporator to the gas exiting the evaporator, which reduces compressor power consumption and improves the efficiency of the A/C system. In the MYs 2012-2016 rule, we considered that IHX technology would be required with the changeover to an alternative refrigerant such as HFO-1234yf, as the different expansion characteristics of that refrigerant (compared to R-134a) would necessitate an IHX. The agencies believe that a 20% improvement in efficiency relative to the baseline configuration can be realized if the system includes an IHX, and a 1.1 g/mi credit and a 0.000124 gal/mi fuel consumption improvement for an IHX.

5.1.3.3.6 Improved-Efficiency Evaporators and Condensers

The evaporators and condensers in an A/C system are designed to transfer heat to and from the refrigerant – the evaporator absorbs heat from the cabin air and transfers it to the refrigerant, and the condenser transfer heat from the refrigerant to the outside ambient air. The efficiency, or effectiveness, of this heat transfer process directly effects the efficiency of the overall system, as more work, or energy, is required if the process is inefficient. A method for measuring the heat transfer effectiveness of these components is to determine the Coefficient of Performance (COP) for the system using the industry-consensus method described in the SAE surface vehicle standard J2765 – Procedure for Measuring System COP of a Mobile Air Conditioning System on a Test Bench.[36] The bench test based engineering analysis that a manufacturer will submit at time of certification. We will consider the baseline component to be the version which a manufacturer most recently had in production on the same vehicle or a vehicle in a similar EPA vehicle classification. The design characteristics of the baseline component (e.g. tube configuration/thickness/spacing and fin density) are to be documented in an engineering analysis and compared to the improved components, along with data demonstrating the COP improvement. This same engineering analysis can be applied to evaporators and condensers on other vehicles and models (even if the overall size of the heat exchanger is different), as long as the design characteristics of the baseline and improved components are the same. If these components can demonstrate a 10% improvement in COP versus the baseline components, EPA and NHTSA estimate that a 20% improvement in overall system efficiency is possible.

5.1.3.3.7 Oil Separator

The oil present in a typical A/C system circulates throughout the system for the purpose of lubricating the compressor. Because this oil is in contact with inner surfaces of evaporator and condenser, and a coating of oil reduces the heat transfer effectiveness of these devices, the overall system efficiency is reduced.[37] It also adds inefficiency to the system to be "pushing around and cooling" an extraneous fluid that results in a dilution of the thermodynamic properties of the refrigerant. If the oil can be contained only to that part of the system where it is needed – the compressor – the heat transfer effectiveness of the evaporator and condenser will improve. The overall COP will also improve due to a reduction in the flow of dilutent. The SAE IMAC team estimated that overall system COP could be improved by 8% if an oil separator was used. EPA and NHTSA believe that if oil is prevented from prevented from circulating throughout the A/C system, an overall system efficiency improvement of 10% can be realized. Whether the oil separator is a standalone component or is integral to the compressor design, manufacturers can submit an engineering analysis to demonstrate the effectiveness of the oil separation technology.

5.1.3.4 Technical Feasibility of A/C Efficiency-Improving Technologies

EPA and NHTSA believe that the efficiency-improving technologies discussed in the previous sections are available to manufacturers today, are relatively low in cost, and their feasibility and effectiveness has been demonstrated by the SAE IMAC teams and various industry sources. The agencies also believe that when these individual components and technologies are fully designed, developed, and integrated into A/C system designs, manufacturers will be able to achieve the estimated reductions in CO_2 emissions and generate appropriate A/C Efficiency Credits, which are discussed in the following section.

5.1.3.5 A/C Efficiency Test Procedures

As proposed, the agencies have two test procedures to determine eligibility for A/C efficiency credits. The two test procedures are the Idle and the AC17 test procedures. The test procedures play different roles depending on the model year for which the test is conducted. For model years 2014 to 2016, there are three options for qualifying for A/C efficiency credits: 1) running the A/C Idle Test, as described in the MYs 2012-2016 final rule, and demonstrating compliance with the CO_2 threshold requirements, 2) running the A/C Idle and demonstrating compliance with engine displacement adjusted CO_2 threshold requirements, and 3) running a newly-developed AC17 test and reporting the test results. For model years 2017-2019, the AC17 test will be the exclusive means manufacturers will have to demonstrate eligibility for A/C efficiency credits, again by reporting the test results. By reporting test results, manufacturers gain access to the credits on the menu based on the design of their AC system. In MYs 2020 and thereafter, however, the AC17 test will be used not only to demonstrate eligibility for efficiency credits, but also to partially quantify the amount of the credit. AC17 test results ("A" to "B" comparison) equal to or greater than the menu value will allow manufacturers to claim the full menu value for the credit. A test result less than the menu value will limit the amount of credit to that demonstrated on the AC17 test. In addition, for MYs 2017-2021, A/C fuel consumption improvement values will be available for CAFE in addition to efficiency credits being available for GHG compliance. These adjustments to the utilization and design of the A/C test procedures were largely a result of new data collected, as well as the extensive technical comments submitted on the proposal. Details of the AC17 test requirements as well as the modified idle test thresholds are described in detail in this section.

In the MYs 2012-2016 final rule, manufacturers were required, starting in MY 2014, to demonstrate the efficiency of a vehicle's A/C system by running an A/C Idle Test as a prerequisite to credit eligibility (the amount of credit determined separately by means of the credit menu). If a vehicle met the emissions threshold of 14.9 g/min CO_2 or lower on this test, a manufacturer was eligible to receive full credit for efficiency-improving hardware or controls installed on that vehicle. The vehicle would be able to receive A/C credits based on a menu of technologies specifying the credit amount associated with each technology. A revised version of this technology menu is described below. For vehicles with a result between 14.9 g/min and 21.3 g/min, a downward adjustment factor was applied to the eligible credit amount, with vehicles testing higher than 21.3 g/min not being eligible to receive credits . The details of this idle test can be found in the MYs 2012-2016 final rule. See 75 FR at 25426-27. This methodology for accessing the credit menu based on the Idle Test results (and threshold requirements) still apply for model years 2014-2016, so this final rule is not making any fundamental changes to the previous rule. EPA is, however providing an optional new threshold requirement for MYs 2014-2016 reflecting both the proposed rule and the comments submitted on the idle test.

In order to establish the value of this eligibility threshold for the MYs 2012-2016 final rule, the EPA conducted an extensive laboratory testing program to measure the amount of additional CO_2 a vehicle generated on the Idle Test due to A/C use. The results of this test program are summarized in Table 5-8, and represent a wide cross-section of vehicle types in the U.S. market. The average A/C CO_2 result from this group of vehicles is the value against which results from vehicle testing will be compared. The EPA conducted laboratory tests on over 60 vehicles representing a wide range of vehicle types (e.g. compact cars, midsize cars, large cars, sport utility vehicles, small station wagons, and standard pickup trucks).

Table 5-8 Summary of A/C Idle Test Study Conducted by EPA at the National Vehicle Fuel and Emissions Laboratory

Vehicle Makes Tested	19
Vehicle Models Tested	29

Model Years Represented (number of vehicles in each model year)	1999 (2), 2006 (21), 2007 (39)
EPA Size Classes Represented	Minicompact, Compact, Midsize, and Large Cars Sport Utility Vehicles Small Station Wagons Standard Pickup Trucks
Total Number of A/C Idle Tests	62
Average A/C CO_2 (g/min)	21.3
Standard Deviation of Test Results ($\pm$ g/min)	5.8

The majority of vehicles tested were from the 2006 and 2007 model years and their A/C systems are representative of the ‘baseline’ technologies, in terms of efficiency (i.e. to EPA’s knowledge, these vehicles do not utilize any of the efficiency-improving technologies described in the credit menu finalized for the MYs 2012-2016 rule). For the MYs 2012-2016 rule, EPA attempted to find a correlation between the A/C CO_2 results and a vehicle’s interior volume, footprint, and engine displacement, but found it to be minimal, as there is significant “scatter” in the test results. This scatter is generally not test-to-test variation, but scatter amongst the various vehicle models and types. This original analysis covered a wide range of vehicle size classes and vehicle types: from compact cars to light-duty trucks, some of which did not have readily-available SAE and CAFE interior volume numbers (i.e. the interior volume for small station wagons and pickup trucks had to be inferred from other published sources). Due to the variability in the data, EPA chose a constant threshold value for the Idle Test performance, which provided access to the credit menu.

Since the previous rule, manufacturers have had the opportunity to run the Idle Test on a wide variety of vehicles and have discovered that even though there may be a small correlation between engine displacement and the Idle Test result, the trend was important enough that small vehicles had higher A/C idle emissions and were more inclined to fail to meet the threshold for the Idle Test than were larger vehicles. Specifically, vehicles with smaller displacement engines had a higher Idle Test result than those with larger displacement engines, even within the same vehicle platform.[38] This was causing some small vehicles with advanced A/C systems to fail the Idle Test. The load placed on the engine by the A/C system did not seem to be consistent, and in certain cases, larger vehicles perform better than smaller ones on the A/C idle test.

When the EPA test data is sorted according to engine displacement, the relationship between engine displacement and idle test result are somewhat apparent, though there is significant variability as is evident in Figure 5-4. The threshold value from the MYs 2012-2016 rule is included in the figure for comparison purposes.

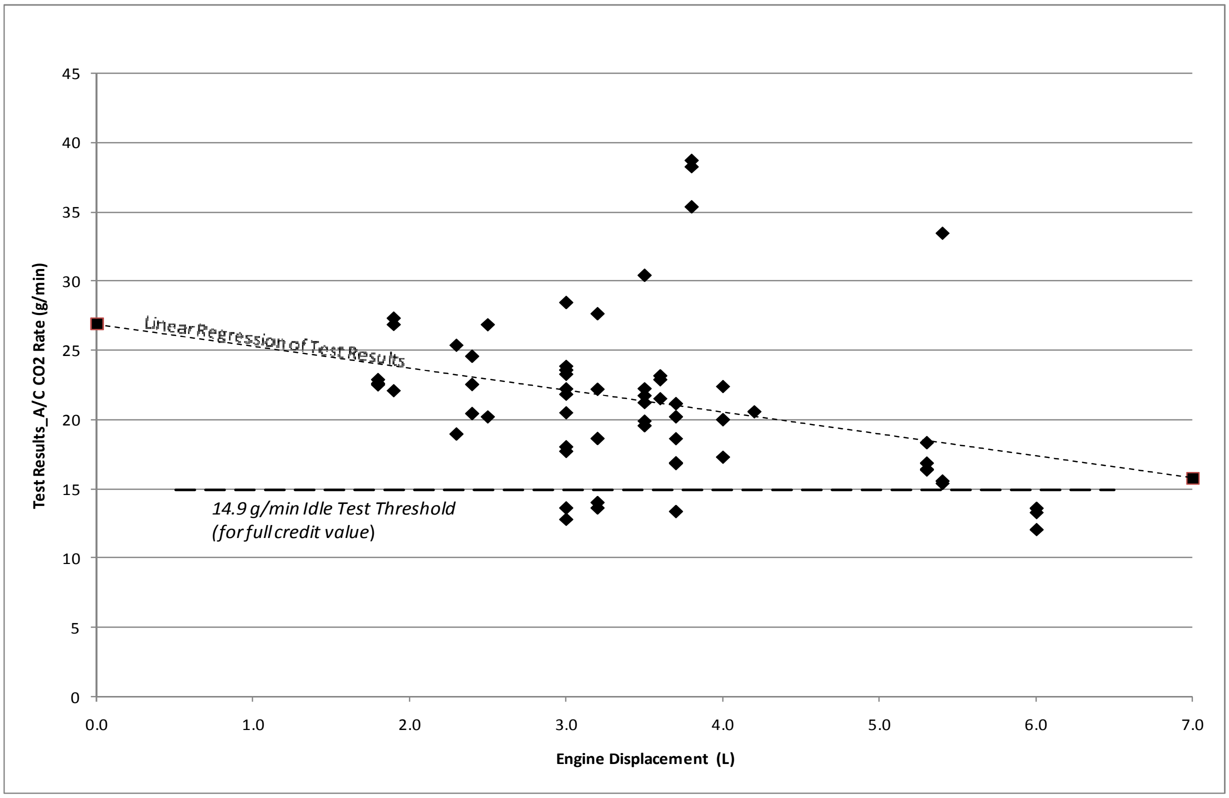


Figure 5-4 Relationship Between EPA A/C Idle Test Results and Engine Displacement.

One factor which may explain part of this observed phenomenon is that the brake-specific fuel consumption (bsfc) of a smaller displacement engine is generally lower at idle than that of a larger displacement engine. At the idle condition, without A/C load applied, a smaller engine is generally more efficient (i.e. has a lower bsfc) than a larger engine, in terms of how well it converts fuel heat energy into power. When additional load from the A/C system is added to the small displacement engine, the bsfc does not improve as dramatically as it does on a larger displacement engine, and if both the small- and large-displacement engines require a similar amount of engine power to run the A/C system, the larger engine will move from a "less-efficient" to "more-efficient" operating condition, whereas the smaller engine remains relatively flat, in terms of bsfc. The result is that a larger displacement engine uses less fuel to run the A/C system, relative to a smaller displacement engine, because its baseline condition (A/C off) is "less-efficient", and the incremental amount of fuel used is lower. The slope of the linear regression line for this data set is -1.58 g/min/L, with a zero intercept of 26.9 g/min.[n]

In the MYs2012-2016 rule, the EPA chose a threshold of 30% improvement on the Idle Test as the threshold for accessing the credit menu (the justification and feasibility

[n] The R^2 for this fit is 0.09 reflecting the scatter and variability of the data. The slope is statistically significant at the 2% confidence level (Significance F) indicating that the slope is statistically significant.

argument is presented again below). This corresponded to a 6.4 g/min reduction from the average Idle Test result (20.5 g/min). Thus the 30% improvement is the average idle test result (20.5 g/min) minus 30% (6.4 g/min) which equals 14.9 g/min (in the previous rule). In this rule, EPA will maintain the 6.4g/min gap between the average emissions (equation of the line) and the threshold. Equation 5-4 results in an idle test threshold which is scaled according to engine displacement, in liters. The threshold equation is overlaid on the data in Figure 5-5. Using this equation, the idle test threshold for a 1.2L engine for example (to receive full credit) would be 18.6 g/min for a 6.0L engine the threshold would be 11.0 g/min.

Equation 5-4 – A/C Idle Test Threshold

$$Idle\ Test\ Threshold = 20.5 - 1.58\ x\ (Engine\ Displacement)$$

In the MYs 2017-2025 NPRM, we acknowledged that the idle test may not fully capture the effect of each and every technology, but believed that the test did reflect the overall efficiency of the vehicle's A/C system under a commonly encountered operating condition. See 76 FR at 74938. For this reason, we continue to allow the use of the original Idle Test through model year 2016. In addition, we have now combined the Idle Test with a displacement-adjusted "threshold," which some manufacturers wishing to use the Idle Test may choose to apply. Overall, however, we now believe that the newly developed AC17 test is a more accurate method for determining A/C fuel use and CO_2 emissions, and that the A/C Idle Test requirement in both its forms can eventually be phased out (as described below).

We believe that part of the variation in the relationship between displacement and Idle Test result that is evident in the figure above, was due to the type of components a manufacturer chose to use in a particular vehicle. Components such as compressors are shared across vehicle model types (e.g. a compressor may be 'over-sized' for one application, but the use of a common part amongst multiple model types results in a cost savings to the manufacturer), rather than being designed for one particular cabin size. Some of the variation may also be due to the amount of cooling capacity a vehicle has at idle. For instance, if the cooling capacity (or cooling performance) of a particular vehicle was less-than-optimal at idle (due to factors such as limitations of the compressor design, pulley ratio, or packaging), this vehicle could produce below-average A/C CO_2 results, because the amount of energy required by the compressor would be lower. Yet at higher engine and/or vehicle speeds, this same vehicle may have cooling capacity typical of other vehicles. Therefore, a test which is limited to one area of A/C operation is limited in its ability to determine overall A/C system efficiency.

Some of this variation between vehicle models may also be due to the efficiency of the fan(s) which draw air across the condenser – since an external fan is not placed in front of the vehicle during the A/C Idle Test, it is the vehicle's radiator fan which is responsible for rejecting heat from the condenser (and some models may do this more efficiently than others). In this case, EPA believes that an SC03-type test – run in a full environmental chamber with a "road-speed" fan on the front of the vehicle – would be a better measure of how a vehicle's A/C system performs under transient conditions, and any limitations the system may have at idle could be counter-balanced by improved performance and efficiency elsewhere in the drive cycle.

Since the MYs 2012-2016 final rule, EPA has received a number of idle test results from several manufacturers. Testing by Ford, General Motors, and Chrysler has shown that there are some significant limitations to the idle test procedure. As mentioned above, there was significant test-to-test variability noted, and many vehicles – especially those with smaller displacement engines – failed to meet the required test threshold (14.9 g/min) to qualify for A/C credits – even when such vehicles are equipped with a significant number of efficiency-improving technologies listed in the menu. These tested vehicles were from upcoming model years and had a variety of air conditioner components and controls strategies (from among the technologies described above and in the menu) implemented. The results are shown in the Table 5-9 and are printed with permission from the manufacturers.

Table 5-9 A/C Idle Test Results from Various Manufacturers

Engine Displacement (liters)	A/C Idle Test Result (gCO_2/min)
1.4	19.4
2.0	22.4
2.0	20.0
2.4	28.0
2.4	18.3
3.5	12.0
3.6	24.0
3.6	16.0
5.7	26.0

The test-to-test variability observed by the manufacturers was significant, and is likely due to high dilution of the exhaust sample (exhaust mass flow is low at idle), which results in greater measurement error, as there is less CO_2 present for sampling than there would be under normal operating conditions. Furthermore, fluctuations in cell ambient conditions (e.g. temperature and humidity), or in the way the driver is positioned in the seat, make accurate test-to-test comparisons of the results difficult to achieve. In Figure 5-5, these new data points from the manufacturers are overlaid onto the idle test data collected in support of the MYs 2012-2016 final rule by the EPA. Most of the EPA vehicles tested over the past two years did not contain a significant amount of efficient air conditioner components (off of the menu list). The manufacturer data is largely consistent with the EPA data. The data support the notion that it might be more appropriate to use an increasing function of emissions as a function of engine displacement for a threshold, rather than the flat function we finalized in the MYs 2012-2016 rule.

The test cells on which Idle Tests are conducted are typically the same cells which are used for FTP testing for criteria pollutants, where the allowable ambient temperature is 68-to-86 °F, and there is no humidity specification. Since there are normal, seasonal fluctuations in humidity level for this type of test cell, controlling the ambient conditions to those specified in the Idle Test procedure is difficult. EPA is modifying the allowable ambient air temperature condition from to 75 ± 2 °F on average to 73-to-80°F on average, and the ambient humidity within the test cell be modified from 50 ± 5 grains of water per pound of dry air to 40-to-60 grains of water per pound of dry air.

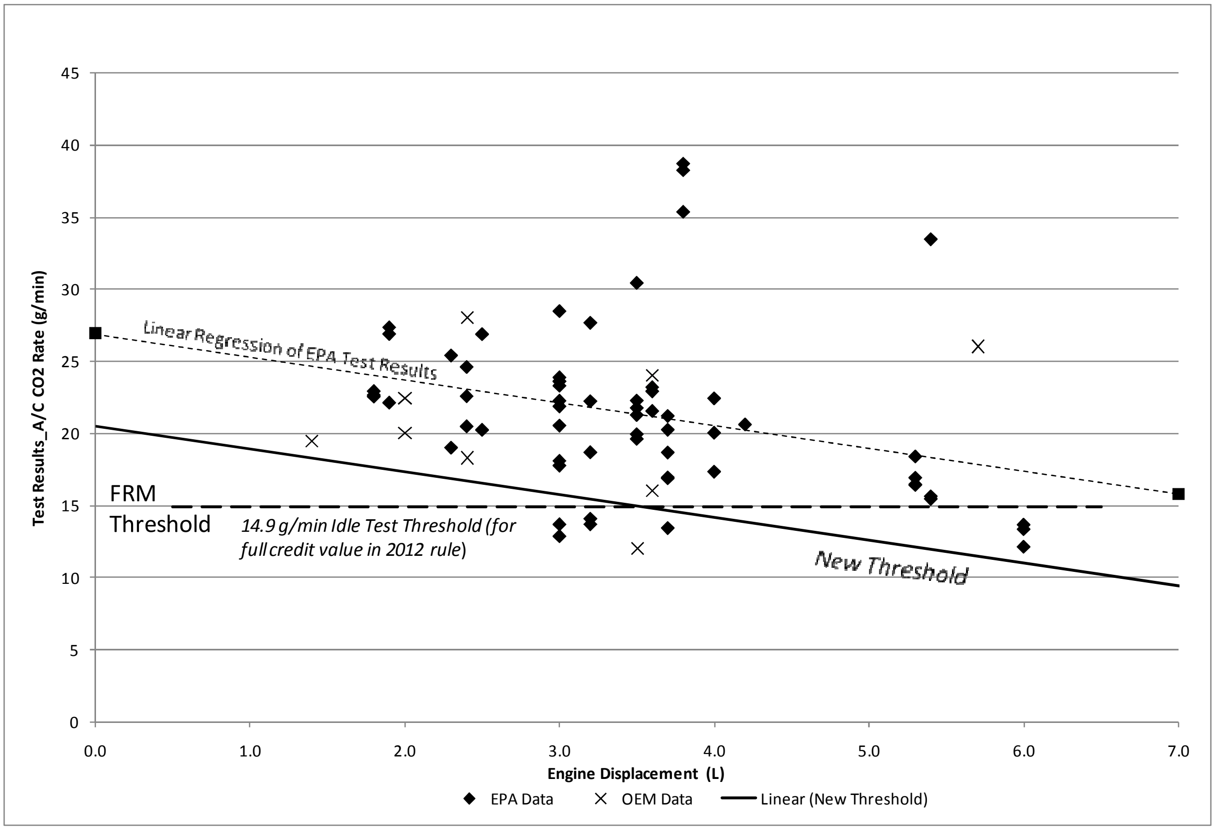


Figure 5-5 EPA A/C Idle Test Results with Results from Various Manufacturers

Based on manufacturer data, with the revised threshold, it is still possible for a vehicle test to have some A/C technologies but still fail to meet the threshold for the credit menu. For the 2014 to 2016 model years, where a manufacturer chooses to run the A/C Idle Test, EPA is allowing partial credits for vehicles that fail to meet the threshold but that show an improvement over the baseline To qualify for the full credit, it will be necessary for each vehicle certified to achieve an A/C CO_2 result less than or equal to the threshold function. As previously described, the threshold function is 30% less than the average value observed in the EPA testing. EPA chose the 30% improvement over the "average" value to drive the fleet of vehicles toward A/C systems which approach or exceed the efficiency of best-in-class vehicles. EPA test results on three vehicle size classes (large car, SUV, and pickup truck) indicate that significant reductions in fuel consumption can be achieved by simply switching A/C control from outside air (OSA) to recirculated cabin air. As shown in Table 5-11, the percentage reduction in the CO_2 and fuel consumption due to A/C use was greater than 30% in all three cases.

Table 5-10 Effect of Outside Air and Recirculated Cabin Air on A/C Idle Test Results (EPA Testing)

Vehicle Type	A/C CO2 Result (g/min)		Change in A/C CO2 w/Recirc (%)
	w/Outside Air	*w/Recirc Cabin Air*	
Large Car	25.9	14.0	-45.9
SUV	17.4	11.4	-34.5

Pickup Truck	14.1	9.0	-36.2

EPA believes the threshold approach will cause manufacturers to tailor the size of A/C components and systems to the cooling needs of a particular vehicle model and focus on the overall efficiency of their A/C systems. However, as explained above, the agency is establishing as proposed an intermediate level of credit for vehicles that do not meet or exceed the Idle Test threshold (either the original fixed threshold from the earlier rule or the displacement-adjusted threshold finalized in this rule), so as not to set an all or nothing threshold to qualify for credits. EPA will allow an intermediate amount of credit as long as the Idle Test performance remains better than the best fit regression obtained from EPA testing. A multiplier would be applied to the credits (based on the menu) such that if the difference between the Idle Test result and the threshold value (hereafter referred to as the "gap") at the vehicle's engine displacement is greater than 6.4g/min, then the multiplier would be 1.0. If the gap is 0.0 g/min or less, then the multiplier would be 0.0, and the multiplier in between would follow a linear function as shown in the following figure. Figure 5-6 shows the change in credit received (y axis) as the idle test result in g/min (x axis) decreases. In the Figure, as the Idle test result (in g/min) decreases, the difference between the Idle test measurement and the threshold increases. The EPA is finalizing an option that allows manufacturers the option of using these threshold adjustments as early as MY 2014.

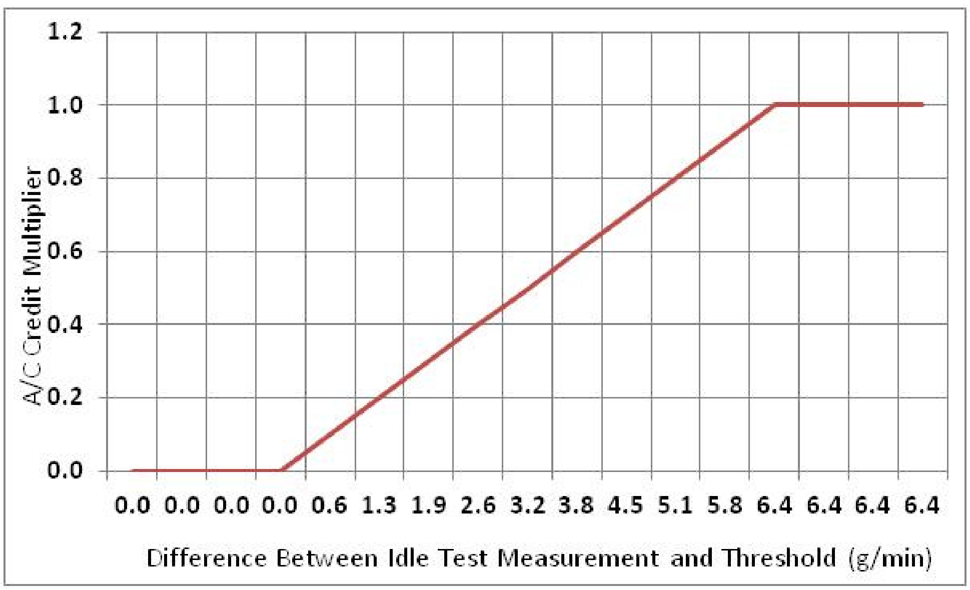


Figure 5-6 EPA A/C Credit Multiplier as a Function of the Difference Between Idle Test Measured and Threshold at any given engine displacement

5.1.3.6 AC17 Test

EPA continues to recognize the limitations of the Idle Test. The primary disadvantage is that the test does not capture the majority of the driving or ambient conditions in the real world when the A/C is in operation, and thus may only encourage the technologies that improve idle performance under narrow temperature conditions. Another limitation is that the narrow range of engine operating conditions present during the Idle Test make it difficult to quantify the incremental improvement of a given technology to generate an actual credit over non-idle operation (without a menu). In order to generate a credit value a more complex test procedure is required that can do an "A" to "B" comparison, where B is with the technology and A is without. There were comments from a number of stakeholders both after promulgation of the MY 2012-2016 rule and in response to the proposed 2017-2025 model year standards reiterating some of these limitations. In preparation for the 2017-2025 NPRM, EPA initiated a study that engaged automotive manufacturers, USCAR, component suppliers, SAE, and CARB in developing a new test procedure for determining A/C system efficiency and credits. This effort also explored the applicability and appropriateness of a test method or procedure which combines the results of test-bench, modeling/simulation, and chassis dynamometer testing into a quantitative metric for quantifying A/C system (fuel) efficiency. The goal of this exercise was the development of a reliable, accurate, and verifiable assessment and testing method while also minimizing a manufacturer's testing burden. The result of this effort is the new AC17 test, which we believe is capable (in part) of detecting the effect of more efficient A/C components and controls strategies during a transient drive cycle, rather than just idle. EPA believes that this new test procedure more accurately reflects the impact that A/C use (and in particular, efficiency-improving components and control strategies) has on tailpipe CO_2 emissions. EPA proposed use of this test, to be phased in starting in MY 2014 as an option, in MYs 2017-2019 as the exclusive means of determining eligibility for A/C efficiency credits, and thereafter as both an eligibility test and as a partial means of determining credit amount. See 76 FR 74938, 74940.

The new AC17 test has four elements: a pre-conditioning cycle, a 30-minute solar soak period; Bag 1 is an SC03 drive cycle at 77 °F (to capture the "pull-down," or post-soak, interior cool-down portion of A/C operation[o]); and Bag 2 is a highway fuel economy cycle (to capture the "steady-state" portion of A/C operation). The test cycle is first run with the A/C on (Bags 1 and 2) and then re-run with the A/C off (Bags 3 and 4). The A/C-related CO_2 emissions are the difference between the A/C on and A/C off test results, with both bag results being averaged (i.e. weighted equally), and the difference between A/C on and A/C off averages producing the overall test result for the vehicle, which represents the incremental CO_2 emissions due to operation of the A/C system. The incremental pull-down and steady-state test results will be reported separately, as well as an average of these two results. EPA believes that this new test cycle will be able to capture improvements in all areas related to efficient operation of a vehicle's A/C system: solar control; efficiency improving components; and efficient control strategies. Below is a depiction of the new test cycle. To assure consistent results for the fuel consumption effect of operating the A/C system, the test is always run in a warm condition, where an EPA Urban Dynamometer Driving Schedule (UDDS) cycle is run at the start of the test sequence, with the A/C off and the solar lamps on. Immediately following this precondition phase, the engine is turned off and the vehicle soaks for 30 minutes with the solar lamps on. At the conclusion of the solar soak, the "pull-down" (rapid cool-down of cabin temperature) phase begins. This phase utilizes the existing SC03

[o] The pull-down period, is the time during which the cabin goes from an elevated temperature state (after having soaked in the heat and sun) to the steady state interior temperature conditions requested by the vehicle occupants.

drive cycle to simulate dynamic, urban driving conditions. Finally, the highway fuel economy test cycle, or HFET, is used to simulate a “steady-state” driving condition, while the A/C system is maintaining the cabin temperature. Each element of this cycle exercises modes of operation seen in everyday use where cabin cooling is needed. By running the vehicle through each of these conditions with and without the A/C system operating, we seek to understand the effect that soak, pull-down, and steady-state conditions have on the fuel consumption for a particular A/C system design or technology. As shown in Figure 5-7, the total time required to run this test on a single vehicle is approximately 4 hours (including A/C on and A/C off phases).

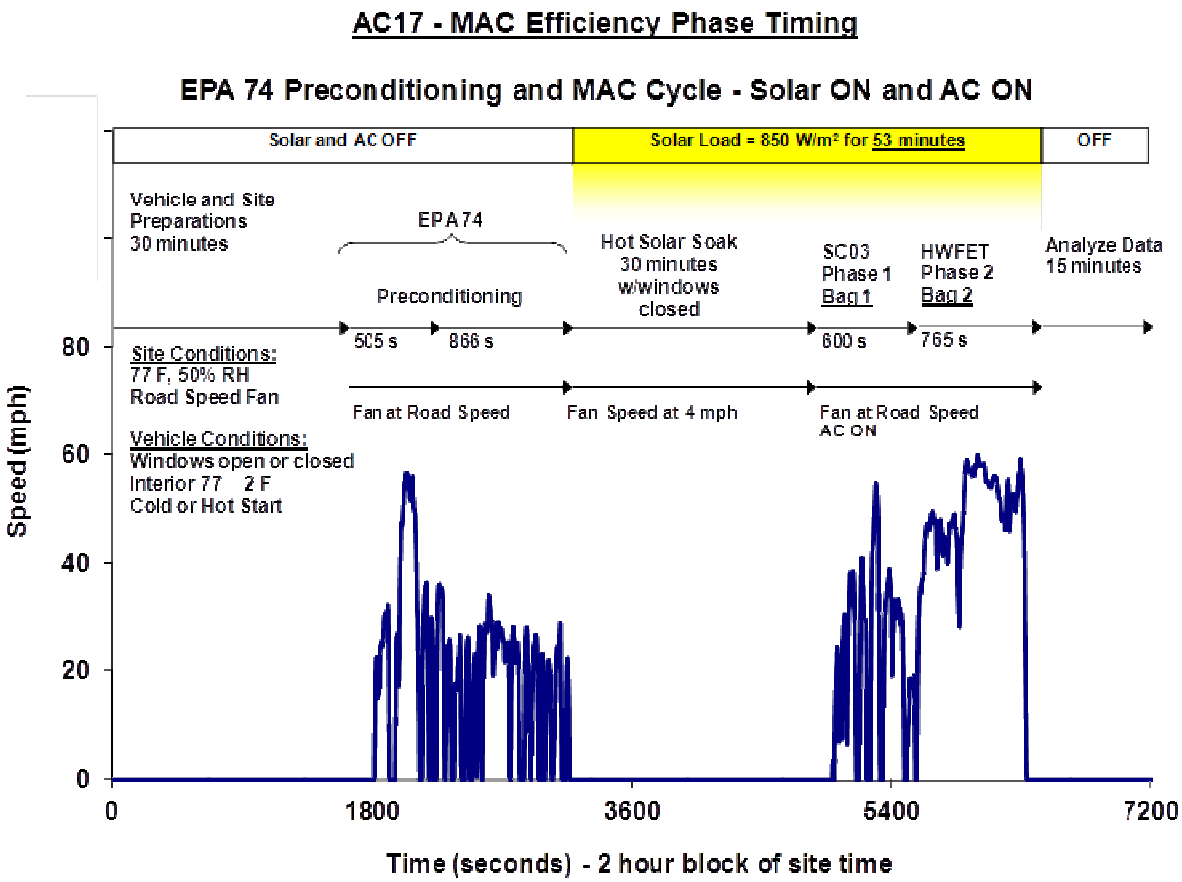


Figure 5-7 AC17 Test

In the NRPM, EPA sought comment on the ambient conditions and system control settings proposed for this test. The ambient temperature for the AC17 test is 77± 2 °F average, and 77± 5 °F instantaneous, with a humidity level in the test cell of 69 ± 5 grains of water per pound of dry air average, and 69 ± 10 grains instantaneous. These ambient temperature and humidity conditions for the AC17 test were chosen because we believed that they represented a common operating condition for A/C use, and that they would allow the effect of many technologies to be demonstrated. The high temperature and humidity conditions of the current SC03 test (95 °F and 100 grains of water per pound of dry air), , while encountered in certain parts of the United States, does not adequately demonstrate the impact of technologies such as variable displacement compressors, as their efficiency benefit is more evident under lower cooling demand conditions. Several commenters noted that that the temperature and humidity tolerances of the test cell conditions may result in voided tests, due to the difficulty in maintaining these conditions throughout a 4-hour test interval. The Alliance asked that humidity requirements be relaxed to avoid voided tests from the proposed 69 $\pm$ 5 average and 69 $\pm$ 10 instantaneous grains of water/pound of dry air. They also asked that ambient temperatures be relaxed from the proposed 77 $\pm$ 3 degrees on average and 77 $\pm$ 5 degrees instantaneous for 95% of the time. They stated that SC03 test facilities were not designed to operate at these temperature and humidity conditions at the required solar load of 850 W/m^2. Ford supported the Alliance comments on AC17 temperature and humidity requirements. However, we believe that widening these tolerances would negatively affect the accuracy of the test – producing either too-high or too-low results for A/C-related CO2 emissions. As such, we are retaining the proposed tolerances for temperature and humidity as proposed, but will stipulate that these tolerances apply only during the emissions measurement portions of the test, and temperature and humidity deviations during the non-emissions measurement portions of the test (e.g. preconditioning and soak) may exceed these tolerances, as long at the duration of the deviation is no more than three minutes. In addition, we will allow manufacturers to use a 30-second moving average on the temperature tolerance, instead of an instantaneous temperature value. We will continue to investigate over time whether temperature and humidity correction factors on the AC17 test results are appropriate, and if so, we will consider their inclusion in the future.

Commenters also noted that an allowable wind speed for the AC17 test cell should be specified for soak and idle conditions, as some air movement within the cell may be necessary to assure proper control of the air temperature and humidity. The agencies agree with this suggestion, and we will allow a nominal wind speed of 4 miles per hour or less during the soak and idle portions of the test cycle. The agencies are also clarifying that the solar lamps are off during the soak prior to the A/C-off portion of the AC17 test (Phases 1 and 2). Concerning the 30-minute soak time, this is a nominal time requirement, and not a precise interval, as is the test involves coordination of the operator exiting and entering the vehicle at the beginning and end of the soak period, as well as activation of the solar lamps. Also, if the windows on the vehicle need to be partially open to allow for instrumentation and wiring to be passed through to the interior, a temporary seal (e.g. foam or tape) can be used to close the window gap.

The control settings for the “A/C ON” portions of the test (Phases 3 and 4 in Figure 5-7) are different for systems with automatic and manual climate controls. Automatic systems will be set to a 72 °F target temperature, with blower (or fan) speed and vent location controlled by the automatic mode. Manual systems will set the temperature selector to full cold, blower speed at its highest setting, and the air supply set to “recirculated air” for the first 185 seconds of Phase 3. At the first idle of Phase 3 (186 to 204 seconds), the blower speed will be set to achieve a nominal 6 volts at the motor, temperature selector will be set to provide 55 °F at the center dash outlet, and the air supply set to “outside air”. The recommended temperature selector and blower control positions for manual systems will be identified by the manufacturer.

5.1.3.7 Analysis of EPA's AC17 Testing

EPA has conducted independent testing on a variety of vehicles and air conditioning technologies on the AC17 test cycle. The purpose of this test effort was to gain insight regarding the appropriateness of the AC17 test for verifying the reduction in CO_2 emissions which are expected from A/C technologies on the efficiency credit menu. EPA tested six vehicles, including three pairs of carlines with some element of different air conditioner systems. The vehicles and A/C technologies evaluated (and yet to be evaluated) in the EPA test program are shown in Table 5-11.

Table 5-11 EPA AC17 Test Vehicles and Technologies

YEAR	MAKE/MODEL	SPECIAL HVAC DETAIL/FEATURES *(if applicable)*
2009/2010	Dodge Journey 2.4L	
2011	Dodge Journey 2.4L	New condenser design
2011	Chrysler 300C 5.7L	
2012	Chrysler 300C 5.7L	Default to re-circulated air above 75 °F
2009	Dodge Caliber 2.4L	
2012	Dodge Caliber 2.4L	Switch from orifice tube to TXV + default to re-circulated air above 75 °F
2009	GM Silverado	
2010	GM Sierra	Reduced reheat
2011	Buick LaCrosse	
2012	Buick LaCrosse	Reduced reheat
2011 or 2012	Ford Fiesta Hatchback	6 speed auto
2011 or 2012	Ford Fiesta Hatchback	6 speed auto with SFE (Super Fuel Economy)
2011	Ford Edge or Ford Explorer	3.5L
2012	Ford Edge or Ford Explorer	2.0L Eco-Boost

5.1.3.7.1 Overview:

In order to verify the appropriateness of the AC17 test as a method to estimate the relative efficiency of different A/C systems in a particular vehicle model, EPA is currently carrying out vehicle testing at the Mercedes-Benz Tech Center located in Ann Arbor, Michigan. The AC17 test is run in a SC03-capable test cell with a road-speed fan and solar lamps, with ambient conditions of 77^oF and 69 grains of water per pound of dry air (about 50% relative humidity).

As noted above, each segment ("A/C On" and "A/C Off") of the AC17 test procedure has four phases: a UDDS preconditioning drive cycle; a 30 minute soak period with a 4MPH wind speed; a SC03 transient drive cycle; and a HWFET quasi-steady-state drive cycle. The test procedure is run twice: first with the A/C "On" and 850 W/m^2 solar load during the soak period and SC03 and HWFET drive cycles; and second with the A/C "Off" and no solar load.

The incremental CO_2 emissions related to fuel used to operate the A/C system is obtained by subtracting the CO_2 emissions when the test procedure is run with the A/C "on" from the CO_2 emissions when the test procedure is run with the A/C "off".

EPA ran AC17 tests on a paired set of the same vehicle model of different model years where an A/C system redesign has occurred between models. The purpose of the testing is to verify the appropriateness of the AC17 test as a method to estimate the relative efficiency of different A/C systems. The AC17 test was repeated between three to five times per vehicle to validate the test-to-test accuracy and feasibility of the AC17 test procedure.

Although the AC17 testing program was ongoing at the time of this final rule, the test results of the first three sets of vehicles appear to reinforce the value of the AC17 test for the purposes of this rule. EPA testing thus far shows low test-to-test variability, we were able to quantify a CO_2 increment between A/C "on" and A/C "off," and we were able to establish a relative CO_2 emissions difference between two A/C systems.

5.1.3.7.2 Summary of Testing To Date

Buick LaCrosse:

The 2011 Buick LaCrosse AC17 test was repeated three times with A/C "off" and another three times with A/C "on." The average A/C "off" CO_2 emission result was 248 g/mi, and the average A/C "on" CO_2 emission result was 267 g/mi, thus resulting in a difference ("delta") of 19g/mi. These results show a very low test-to-test variability. Similarly, the average A/C "off" fuel economy was 33.5 mpg, and the average A/C "on" fuel economy was 31.1 mpg, or about a 7% reduction in average fuel economy).

EPA also tested a 2012 Buick LaCrosse that has a reduced reheat strategy and an A/C economy mode that will turn "on" and "off" the compressor. For the reduced reheat strategy A/C system on this vehicle, the average A/C "off" CO_2 emission result was 221g/mi, and the average A/C "on" CO_2 emission result was 255.8 g/mi; thus resulting in a difference ("delta") of 35g/mi. The reduced reheat strategy (which can generate a CO_2 credit of up to 1.5 g/mi for cars and 2.2 g/mi for trucks) should have resulted in a lower delta on the AC17 test, but in this case, the 2012 vehicle has an automatic start-stop feature, which turns off the engine when the vehicle is stopped and the A/C is off. This engine-off feature resulted in the 2012 vehicle having an A/C off CO_2 emissions result that was 27 g/mi lower than the 2011 vehicle's, which resulted in a larger A/C on-to-A/C off delta for the2012 vehicle. This does not necessarily indicate that the 2012 vehicle's A/C system is less efficient than the 2011 system, but illustrates that AC17 is valid only when comparing vehicles with similar A/C and powertrain systems. When the 2012 vehicle was run with the A/C on and the "ECO" mode enabled (ECO mode is activated via a dash button, which when pressed, allows the engine start-stop feature to function under certain conditions while the A/C is on), the AC17 result was 241.6 g/mi (14.2 g/mi lower than the non-ECO-mode result), resulting in a delta of 21 g/mi, which is much closer to the 19 g/mi result observed on the 2011 vehicle. In the case of the 2011 to

2012 Buick LaCrosse comparison, an engineering analysis would be required to demonstrate that additional technology (or technologies) present on the vehicle result in improved efficiency of the A/C system.

GM Silverado:

The second pair of vehicles was a 2009 GM Silverado and a 2010 GM Sierra. Both vehicles have the same platform. The 2009 GM Silverado had a manual A/C system and the 2010 GM Sierra had an A/C system with and automatic reheat reduction strategy. The Silverado had average A/C "off" CO_2 emissions of 444 g/mi and fuel economy of 18.9 mpg, and average A/C "on" CO_2 emissions of 481 g/mi and fuel economy of 17.4 mpg. This corresponds to a CO_2 emissions delta of 37g/mi. Again, the test-to-test variability was low.

The 2010 Sierra, had average A/C "off" CO_2 emissions of 410 g/mi and fuel economy of 20.8 mpg, and average A/C "on" CO_2 emissions of 452.2 g/mi and fuel economy of 18.5 mpg, with low test-to-test variability. The CO_2 emissions delta is thus 41 g/mi.

Here, the AC17 test between the redesigns was closer in value. However, the "more efficient" 2010 system delta was still higher than the "less efficient" 2009 system, which on the surface, seems counterintuitive. However, the A/C system settings on the AC17 test for 'automatic' and 'manual' systems are not equivalent, and comparing the results between these systems not valid for the purpose of demonstrating the effect of particular A/C technologies. Where possible, we expect that manufacturers will use the AC17 test for comparing the performance of vehicles with identical or substantially similar A/C control systems (manual vs automatic for example).

Further analysis of the AC17 test results has shown that there are differences in the A/C system operation on automatic- and manually-controlled systems which explain why these differences can affect the A/C load applied to the engine, and the resulting CO_2 emissions. EPA is examining data such as instrument panel temperature, compressor inlet temperature, coolant temperature, engine control algorithms, recirculation control to understand test result differences among similar vehicles, and trying to identify patterns which may improve our understanding of how AC17 test results and/or engineering analyses will be used to demonstrate the effectiveness of advanced A/C technologies.

Chrysler 300

The third pair of vehicles was the 2011 and 2012 Chrysler 300C with a 5.7L engine. The 2011 Chrysler 300C tested is a rear wheel drive vehicle, and the 2012 Chrysler 300C is an all wheel drive vehicle. The 2012 Chrysler 300C A/C system has a default to automatically recirculate air when the cabin temperature is 75^{o}F.

The 2011 Chrysler 300C had average A/C "off" CO_2 emissions of 328.4 g/mi and fuel economy of 25.4 mpg, and average A/C "on" CO_2 emissions of 358 g/mi and fuel economy of 23.4 mpg. This corresponds to a CO_2 emissions delta of 30 g/mi.

The 2012 Chrysler 300C had average A/C “off” CO_2 emissions of 348.7 g/mi and fuel economy of 24.2 mpg, and average A/C “on” CO_2 emissions of 378.5 g/mi and fuel economy of 22.1 mpg. The CO_2 emissions delta is thus 30 g/mi.

Again, for both vehicles, the test-to-test variability was low. Here, both systems have the same CO_2 emissions delta. Possibly due the all wheel drive driveline, the A/C “off” CO_2 emissions of the 2012 vehicle are higher than the 2011 vehicle, and therefore, the 2012 vehicle has a comparatively more efficient A/C system operation than the 2011 vehicle, as both vehicles had the same delta of 30 g/mi CO_2.

In each of the three vehicle comparisons, there were confounding factors which prevented a direct assessment of the A/C technology alone: in the case of the GM trucks, it was automatic vs. manual control of the A/C system; in the case of the Buick LaCrosse, it was ECO mode vs. non-ECO mode; in the case of the Chrysler 300, it was rear wheel drive vs. all wheel drive. In follow-on testing, EPA will be testing vehicle pairs with A/C control strategies, powertrains, and drivelines which are as close to identical as possible. The preliminary EPA testing has shown that the AC17 test is capable of low test-to-test variability, and is suitable for evaluating the relative efficiency improvement of A/C technologies, when confounding factors are minimized. EPA also believes that in cases where comparison of the AC17 results do not directly demonstrate the effectiveness of a technology, the test results can still be useful within an engineering analysis for justifying the test methodology to determine A/C CO_2 credits. EPA will analyze the data from the other vehicles as soon as they are collected, and in the future, EPA plans to collect more data on this test procedure and monitor the results of the reported results of AC17 starting in MY 2014.

5.1.3.8 Options for Generating A/C Efficiency Credits

In MYs 2014-2016, to demonstrate that a vehicle’s A/C system is delivering the efficiency benefits of the new technologies on the credit menu, instead of running the Idle Test , manufacturers will have the option to run the AC17 test procedure on each vehicle platform that incorporates the new, credit-generating technologies, and report the results from all 4 phases of the test to EPA. In addition to reporting the test results, EPA is requiring that manufacturers provide information about each test vehicle and its A/C system (e.g. vehicle class, model type, curb weight, engine size, transmission type, interior volume, climate control type, refrigerant type, compressor type, and evaporator/condenser characteristics).

For model years 2017 and beyond, EPA is eliminating the A/C Idle Test and threshold requirement, and replacing it with the AC17 test. Thus, for MYs 2017 and beyond, manufacturers will run the AC17 test to quantify the A/C-related CO_2 emissions on a limited number of vehicles. For model years 2017 through 2019, to access the A/C credit menu (i.e. to be eligible to generate A/C efficiency credits), manufacturers will report the results of AC17 test results on the required number of vehicles to EPA as part of the certification process. For model years 2020 and beyond, manufacturers will be required to demonstrate that the results (delta between A/C on and A/C off) of the new model year vehicle are lower than the results (delta) from a previously-tested ‘baseline’ vehicle. This comparison helps to validate that the A/C technologies for which credit is generated are actually reducing A/C-related CO_2 emissions, To receive the full amount of A/C credit generated from the menu, the difference between the new and baseline results should be equal to or greater than the sum of the menu-based credits for technologies present on the new vehicle. The baseline vehicle should be one with characteristics which are similar to the new vehicle, but not be equipped with A/C efficiency-improving technologies, or be equipped with those technologies without the technologies being implemented (e.g. forced cabin air recirculation). This baseline vehicle would be one previously tested by the manufacturer, where AC17 results were reported to the EPA, and will be from the same platform, but from a prior (re)design.

We recognize that it may not be possible to find a baseline vehicle that is identical (in terms of powertrain characteristics, as well as aerodynamic and parasitic losses) to the new vehicle. The Alliance and others commented that any comparison to a prior redesign would be an unfair comparisons because of other changes on the vehicle that may have occurred. However, as we described in section 5.1.3 above and Chapter 5 of the EPA RIA, based on the simulated behavior of A/C systems in a variety of vehicles, we believe that the amount of fuel used to operate the A/C system is largely dependent on the compressor size and cooling capacity of the system, and much less dependent on engine displacement or efficiency. As such, we believe that it is technically appropriate for manufacturers to compare vehicles from different generations of redesign cycles in order to demonstrate that their efficient A/C systems can provide CO_2 and fuel consumption reductions commensurate to the amount of credit that a particular vehicle can generate.

For cases where a comparison of a baseline vehicle to a new vehicle with additional A/C technologies (which generate additional credits) is possible, the difference between the baseline and new AC17 test results must be equal to or greater than the amount of additional credit generated for the new vehicle for the vehicle to receive the full credit (based on the technology menu). In cases where the A/C technologies between the baseline and new vehicle are identical, we expect that the difference between the baseline and new vehicle AC17 test results should be near zero. If the difference in AC17 test results on this “same technology” comparison was greater than zero (i.e. the “new” vehicle had greater AC17 emissions than the baseline vehicle), or in cases where no baseline comparison test result is available (e.g. a brand-new platform has been created), we will require that manufacturers submit an engineering analysis that justifies the generation of credits. The engineering analysis would describe why the new vehicle had higher AC17 results, or why a comparison to a baseline vehicle AC17 test result is neither available nor appropriate, and why the generation of credits in either case is justified

However, starting in MY 2020, if the difference between the baseline and new AC17 test results is less than the sum of the menu credit generated for the new technology (or technologies), and an engineering analysis cannot justify a higher-than-expected AC17 test result, partial credit can still be generated. A manufacturer can use the credit scaling factor in Equation 5-5, which is proportional to the ratio of the difference in the AC17 test results divided by the menu credit amount and can be applied to the new technology menu credits as follows::

Equation 5-5 – AC17 Credit Scaling Factor

Credit Scaling Factor = (Baseline AC17 Result – New AC17 Result) ÷ Sum of New Technology Menu Credits

For MY 2017 (and optionally for MYs 2014-2016), the AC17 testing will first be required on the highest-production-volume configuration from each platform for which credits are generated. Because the new A/C test requires significant amount of time for each test (nearly 4 hours) and must be run in SC03-capable facilities, EPA believes that it is appropriate to limit the number of vehicles a manufacturer must test in any given model year by limiting the testing to no more than one vehicle from each platform for each model year. For the purpose of the AC17 test and generating efficiency credits, a single platform will be defined in a manner similar to that which EPA has used to define a "car line" (see 40 CFR §600.002-08), and reads as follows:

"Platform" means a segment of an automobile manufacturer's vehicle fleet in which the vehicles have a degree of commonality in construction (primarily in terms of body and , chassis design). Platform does not consider the model name, brand, marketing division, or level of decor or opulence, and is not generally distinguished by such characteristics as powertrain, roof line, number of doors, seats, or windows. A platform may include vehicles from various fuel economy classes, including both light-duty vehicles and light-duty trucks/medium-duty passenger vehicles.

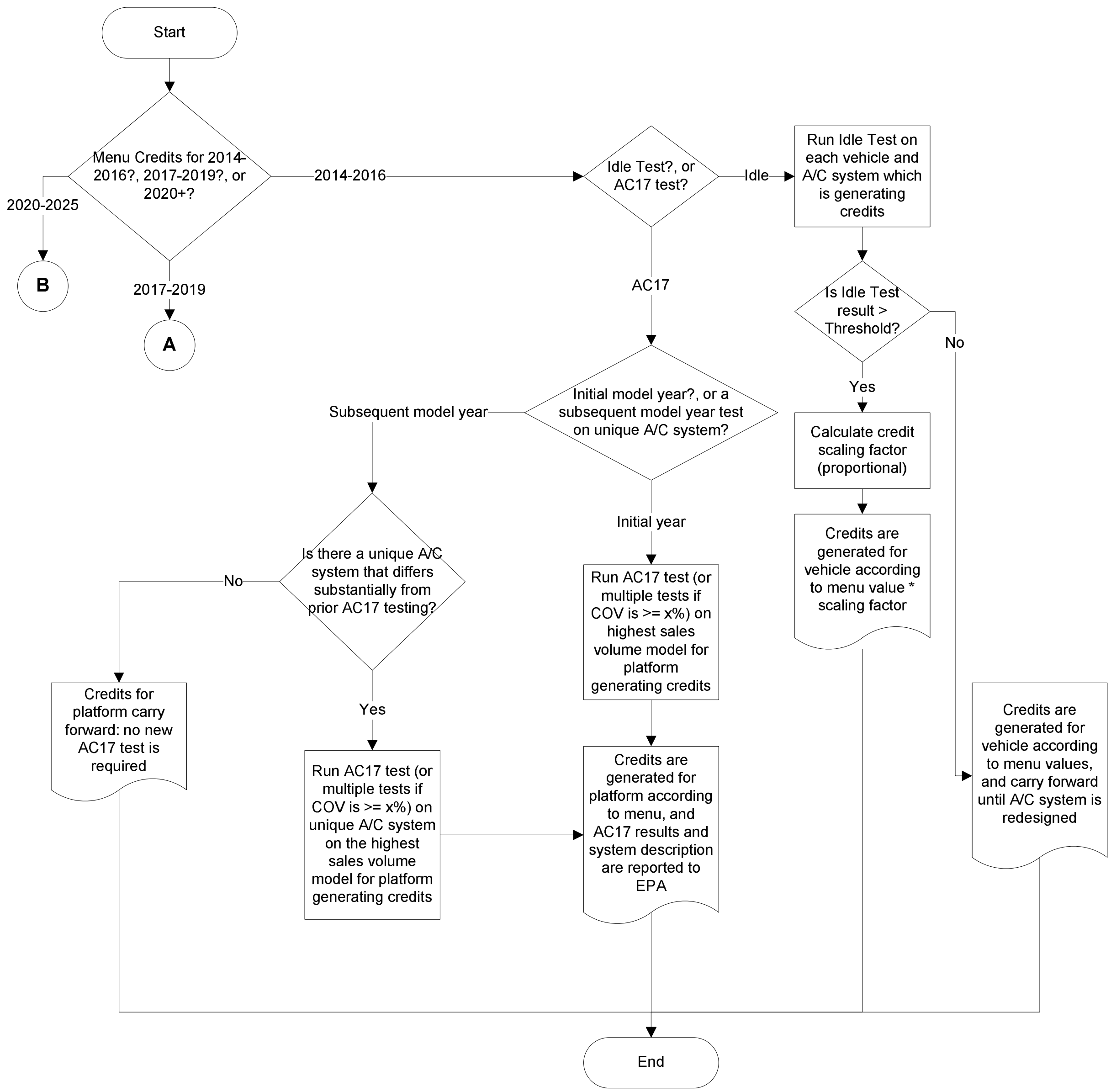
This definition was modified from the proposal based on comments received. In particular, we agree with the Alliance that vehicle powertrain is not a key characteristic of a platform for purposes of this rule, and the final definition of "platform" clarifies this.

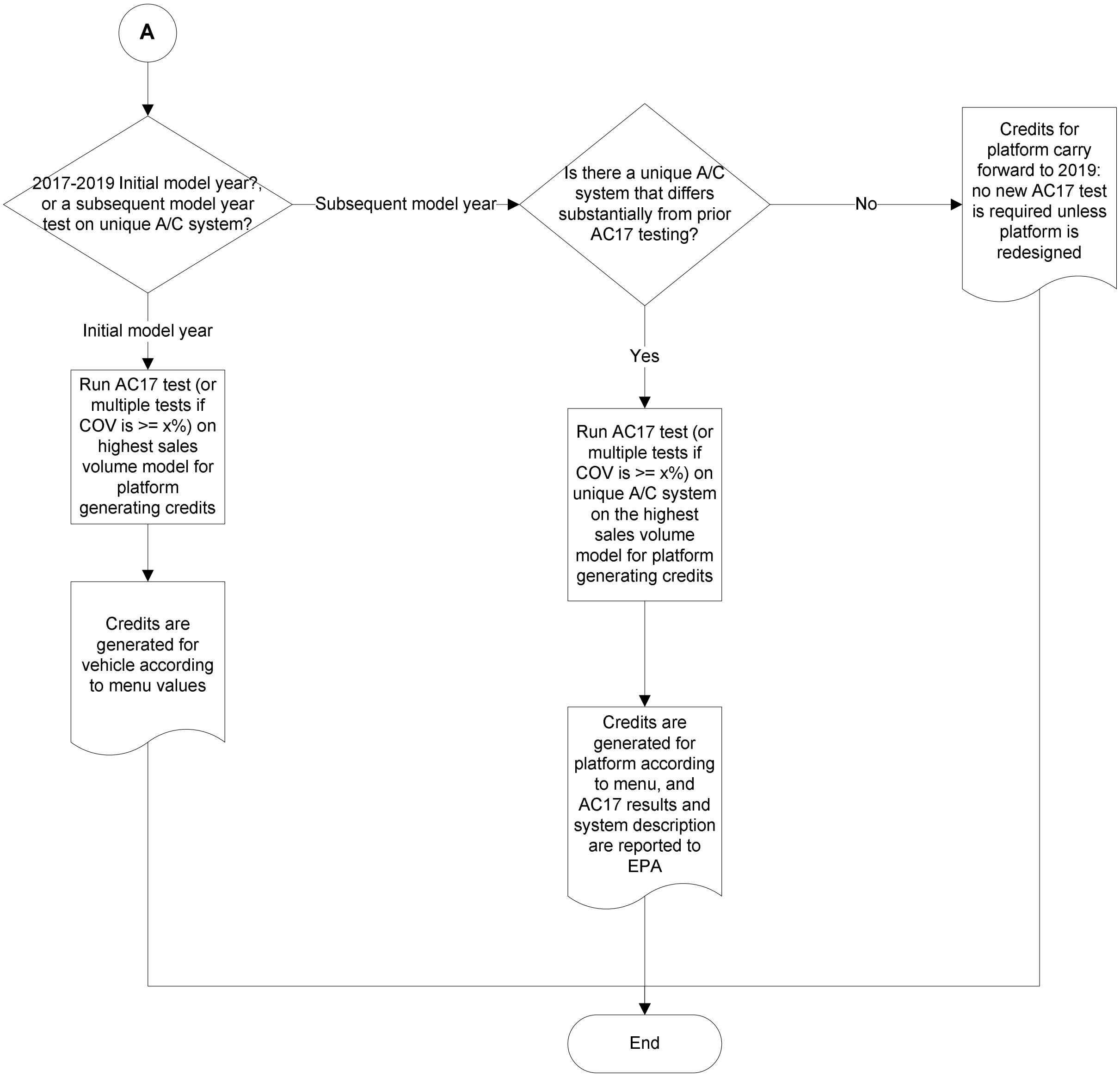
EPA recognizes that a vehicle manufacturer may only utilize one or two A/C system designs across many vehicle models within a platform, and it is not the intention of EPA that a manufacturer measure the performance of each A/C system design on each model within the platform, but simply that each A/C system design be tested on the highest expected sales volume configuration within each platform, as defined above. For the first year in which a manufacturer performs AC17 testing – either as required in model year 2017, or as an option to the Idle Test in model years 2014 through 2016 - what the manufacturer expects to be the highest sales volume configuration from a given platform will need to be tested. In subsequent model years, a unique A/C system design, where it exists and has not yet been tested in this program, would be tested, continuing each model year until all A/C system designs have been tested in their highest expected sales volume models.

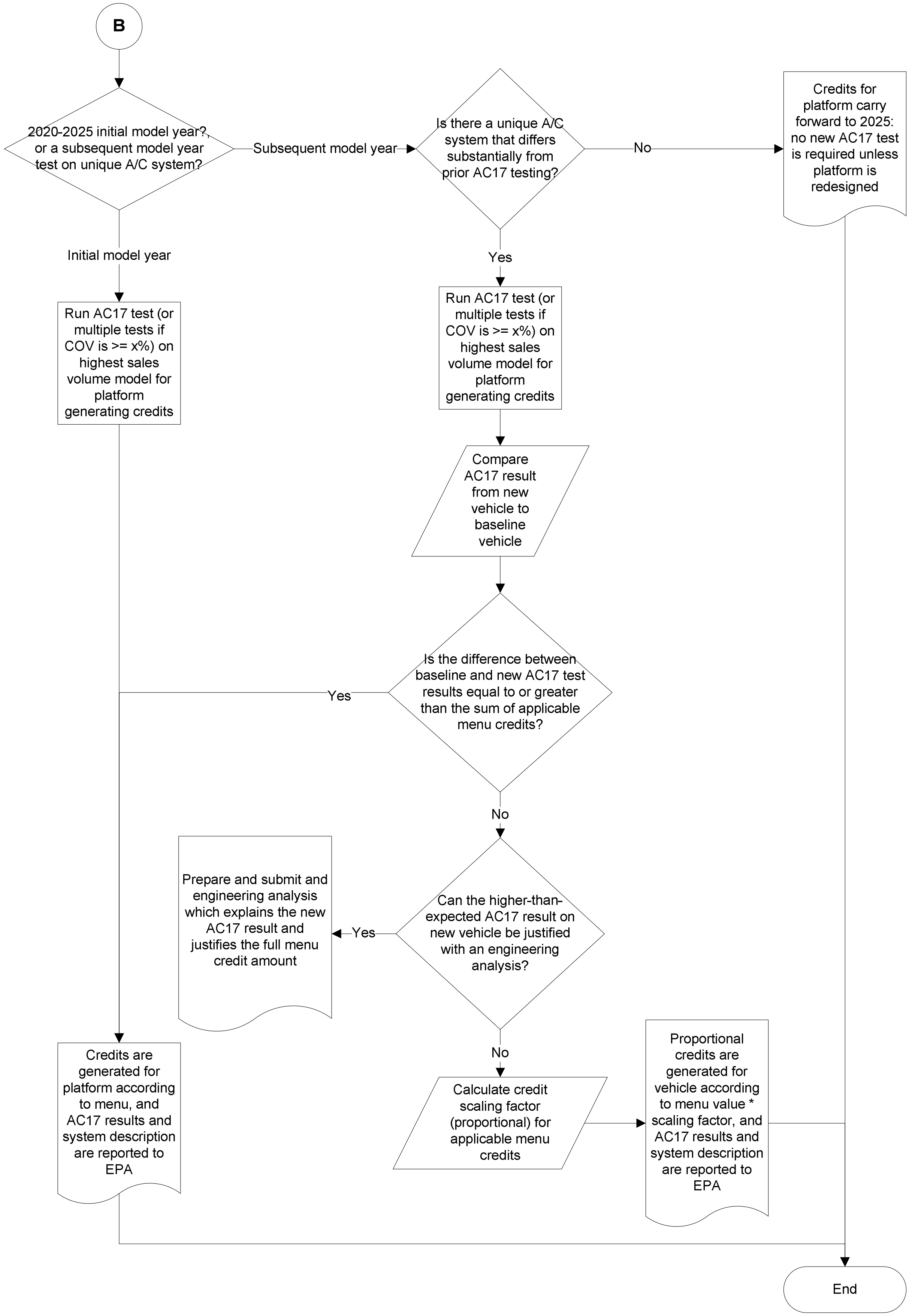
For the purpose of this rule, a "unique A/C system design" will be defined as one in which substantially-different A/C component designs or types and/or system control strategies are used (e.g. fixed-displacement vs. variable-displacement compressor, orifice tube vs. thermostatic expansion valve, manual vs. automatic climate control, single vs. dual evaporator, etc.). A/C system designs which have similar cooling capacity, component types, and control strategies, yet differ in terms of compressor pulley ratios or condenser or evaporator surface area will not be considered to be unique designs. The test results from one system design will apply to all design variants. EPA will require that manufacturers use good engineering judgment to identify the unique A/C system designs which will require AC17 testing in subsequent model years. Manufacturers would indicate the basis for their engineering judgment at certification.

Starting in MY 2017, for each model year in which a manufacturer is using the AC17 test (including optionally in MYs 2014-16), no more than one vehicle from each platform will need to be tested on the AC17 test. A manufacturer may choose to perform replicate tests (to address concerns about test-to-test variability or to generate more robust data to support credits for later use), but data from a single test is acceptable, As long as the necessary AC17 tests are performed each model year, the credits generated for all model configurations within a given platform can be carried over until there is a significant change in the platform design, at which point a new AC17 test on the highest sales volume configuration of the new platform design will be required. The following flowcharts in Figure 5-8 illustrate the process for determining the testing and reporting requirements for generating A/C efficiency credits.

Figure 5-8 Process for A/C Efficiency Credit Generation: Model Years 2014 through 2025


Start
Menu Credits for 2014-2016?, 2017-2019?, or 2020+?
2020-2025
B
2017-2019
A
2014-2016
Idle Test?, or AC17 test?
Idle
Run Idle Test on each vehicle and A/C system which is generating credits
Is Idle Test result > Threshold?
No
Yes
Calculate credit scaling factor (proportional)
Credits are generated for vehicle according to menu value * scaling factor
Credits are generated for vehicle according to menu values, and carry forward until A/C system is redesigned
AC17
Initial model year?, or a subsequent model year test on unique A/C system?
Subsequent model year
Initial year
Run AC17 test (or multiple tests if COV is >= x%) on highest sales volume model for platform generating credits
Credits are generated for platform according to menu, and AC17 results and system description are reported to EPA
Is there a unique A/C system that differs substantially from prior AC17 testing?
No
Yes
Credits for platform carry forward: no new AC17 test is required
Run AC17 test (or multiple tests if COV is >= x%) on unique A/C system on the highest sales volume model for platform generating credits
End


A
2017-2019 Initial model year?, or a subsequent model year test on unique A/C system?
Subsequent model year
Initial model year
Run AC17 test (or multiple tests if COV is >= x%) on highest sales volume model for platform generating credits
Credits are generated for vehicle according to menu values
Is there a unique A/C system that differs substantially from prior AC17 testing?
No
Yes
Credits for platform carry forward to 2019: no new AC17 test is required unless platform is redesigned
Run AC17 test (or multiple tests if COV is >= x%) on unique A/C system on the highest sales volume model for platform generating credits
Credits are generated for platform according to menu, and AC17 results and system description are reported to EPA
End


B
2020-2025 initial model year?, or a subsequent model year test on unique A/C system?
Subsequent model year
Is there a unique A/C system that differs substantially from prior AC17 testing?
No
Credits for platform carry forward to 2025: no new AC17 test is required unless platform is redesigned
Initial model year
Yes
Run AC17 test (or multiple tests if COV is >= x%) on highest sales volume model for platform generating credits
Run AC17 test (or multiple tests if COV is >= x%) on highest sales volume model for platform generating credits
Compare AC17 result from new vehicle to baseline vehicle
Is the difference between baseline and new AC17 test results equal to or greater than the sum of applicable menu credits?
Yes
No
Prepare and submit and engineering analysis which explains the new AC17 result and justifies the full menu credit amount
Yes
Can the higher-than-expected AC17 result on new vehicle be justified with an engineering analysis?
No
Credits are generated for platform according to menu, and AC17 results and system description are reported to EPA
Calculate credit scaling factor (proportional) for applicable menu credits
Proportional credits are generated for vehicle according to menu value * scaling factor, and AC17 results and system description are reported to EPA
End

In addition, EPA is requiring that manufacturers provide detailed information about the A/C systems in vehicles tested, both baseline and new, as well as a plot with the interior temperature of both vehicles, to confirm that there is equivalent or better cooling system performance in the new vehicle configuration. EPA requires that interior temperature be measured at three locations: at the outlet of the center duct on the dash panel, and behind the driver and passenger seat headrests. For the headrest locations, the temperature measuring devices shall be nominally 30 millimeters behind the center of the headrest.

5.1.3.9 A/C Efficiency Credits and Quantification of Credits

EPA and NHTSA believe that it is possible to identify the A/C efficiency-improving components and control strategies most likely to be utilized by manufacturers and will continue to assign a CO_2 credit and fuel consumption improvement value to each. In addition, the agencies recognize that to achieve the maximum efficiency benefit, some components can be used in conjunction with other components or control strategies. Therefore, the system efficiency synergies resulting from the grouping of three or more individual components are additive, and will qualify for a credit commensurate with their overall effect on A/C efficiency. A list of these technologies – and the amount of credit (and estimated fuel consumption improvement value derived from the credit) associated with each technology – is shown in Table 5-12. If more than one technology is utilized by a manufacturer for a given vehicle model, the A/C credits or fuel consumption improvement values can be added, but the maximum credit and fuel consumption improvement value possible is limited to 5.0 g/mi for cars (equivalent to 0.000563 gal/mi) and 7.2 g/mi (equivalent to 0.000810 gal/mi) for trucks.

In the proposal, NHTSA sought comment on setting fuel specific conversion factors. The agencies did not receive any comments on the use of fuel specific conversion factors. The agencies believe that since both the CAFE target curves and the AC credits are derived using the gasoline conversion factor, it is appropriate to use the gasoline conversion factor for all fuels. If different conversion factors were used based on the type of fuel, there would be misalignment between the A/C compliance credits, which would be based on the type of fuel the vehicle uses, and the stringency of the target curves, which are based on gasoline. Therefore, the agencies are finalizing the use of the gasoline conversion factor to determine A/C improvement values for all vehicles.

Table 5-12 Efficiency-Improving A/C Technologies and Credits

Technology Description	A/C CO_2 Emission and Fuel Consumption Reduction	Car A/C Credit and Adjustment (g/mi CO_2 and gal/mi)	Truck A/C Credit and Improvement (g/mi CO_2 and gal/mi)*
Reduced reheat, with externally-controlled, variable-displacement compressor	30%	1.5 (*30% of 5.0 g/mi impact*) / 0.000169	2.2 (*30% of 7.2 g/mi impact*) / 0.000248
Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor	20%	1.0 / 0.000113	1.4 / 0.000158
Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	30%	1.5 / 0.000169	2.2 / 0.000248
Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis)	20%	1.0 / 0.000113	1.4 / 0.000158
Blower motor control which limit wasted electrical energy (e.g. pulsewidth modulated power controller)	15%	0.8 / 0.000090	1.1 / 0.000124
Internal heat exchanger (or suction line heat exchanger)	20%	1.0 / 0.000113	1.4 / 0.000158
Improved evaporators and condensers (with engineering analysis on each component indicating a COP improvement greater than 10%, when compared to previous design)	20%	1.0 / 0.000113	1.4 / 0.000158
Oil Separator (internal or external to compressor)	10%	0.5 / 0.000056	0.7 / 0.000079

* This factor is a gasoline conversion from CO_2 using 8887 g/CO_2 per mpg, NHTSA will set this constant independent of fuel.

Even though EPA is finalizing a design-based A/C credit program that introduces some minor revisions to the menu values from the MYs 2012-2016 rule, EPA continues to believe that a full performance-based test procedure is the most appropriate way for quantifying A/C credits. Performance-based procedures place no limits on the technological choices made by a manufacturer to improve efficiency. Ideally, performance based standards would be the most appropriate method of quantifying A/C credits, however there are many challenges to accurately quantifying a small incremental decrease in emissions and fuel consumption compared to a relatively large tailpipe emissions and fuel consumption rate. For example, it would be nearly impossible to distinguish and measure the impact of a 0.5g/mi improvement in tailpipe emissions due to an improved oil separator system incremental to a tailpipe 250g/mi test procedure result. The 0.5 g/mi increment would be well within the noise of a test measurement or test-to-test variability. Even if a number of the technologies were to be packaged together to account for a 5.0g/mi improvement, this is still only 2% of the tailpipe emissions value and still may be within test-to-test variability.

The other major challenge to quantifying credits is that it is not practical (from a compliance standpoint) to measure the CO_2 emissions from a vehicle with and without a series of technologies that include hardware and software integrated in a complex fashion. This could only be done with an “A” to “B” comparison where the “B” condition includes the technologies and the “A” condition does not. Such A to B test comparisons require the manufacture of a prototype vehicle that is in all respects identical to the certified vehicle with the exception that the technologies being evaluated are removed. This would be impossible to do for every vehicle certified for a fuel economy test. It would even be prohibitive for a single vehicle demonstration for each manufacturer. This might only be practical on a single vehicle research level program as was done in the IMAC study. The comparison of the AC17 test result to AC17 result for the baseline vehicle with the older technology will likely show a small change in emissions, based on the vehicle simulation results presented above. A more direct comparison of individual technologies is likely to give even more accurate quantification of credits such that the menu may no longer be required.

The IMAC study successfully demonstrated that there are methods by which the efficacy of technologies can be measured. In the IMAC study, the efficiency of A/C components were measured on a test bench where the conditions can be precisely controlled. Test bench measurements are, by their nature, much more repeatable than chassis dynamometer tests. They can also easily be used to do A to B comparisons of technology effectiveness since components can be relatively easily swapped out. The limitations of test bench measurements primarily lie in the fact that they cannot capture the impact of the component integration into the vehicle. The test bench only measures the efficiency of the A/C components, it cannot account for the controls strategy (for example), such as forced recirculation, not defaulting to reheat, and smart cycling of fixed displacement compressors. Another disadvantage of test benches are that there are few such facilities available in the United States and typical OEMs do not possess such extensive test benches as they do not manufacture A/C components.

One option to circumvent the limitations of both the test bench and the chassis tests are to merge the two in a combined test procedure that will utilize the strengths of each to supplement the weaknesses of the other. The test bench can generate the A to B comparison portion of the credit on the hardware changes, while the chassis test generates the A to B comparison of the (software) controls strategy changes.

An A/C test bench typically measures the efficiency of a system by measuring its Coefficient of Performance (COP). The COP of a heat pump is the ratio of the change in heat at the output to the supplied work (also equivalent to the SEER seasonal energy efficiency ratio rating on a residential A/C unit).[p] The IMAC procedure employed the SAE procedure J2765 in order to bench test systems in a fashion that reflects national average A/C usage. This test procedure could be used to generate the efficiency of any production A/C system. The challenge lies in the comparison to the baseline "A" system for the A to B comparison. This could be done either with a defined hardware baseline system or a typical baseline COP value agreed upon by the industry.

Combining the bench test together with a chassis test requires a model, simulation, or some calculation procedure (algorithm) to convert the test bench results to fuel economy and GHG emissions. There are a number of options for this model. The Lifecycle Climate Performance or LCCP model (also known as SAE J2766), developed by General Motors in partnership with SAE, NREL, EPA, is one such model, and was utilized for the IMAC project. While the LCCP model took into account many factors concerning lifecycle emissions and fuel use (including the energy needed to manufacture a particular refrigerant), it may be possible to employ a portion that model, and only discern the effect of the A/C system efficiency of annualized fuel use due to A/C operation. As updates to the LCCP model occur, EPA will evaluate the appropriateness of using such tools to quantify the effect of efficiency-improving A/C technologies. Another option is for the test bench to produce charts like the one in Figure 5-4. This can then be used as an input into EPA's vehicle simulation tool. Whatever the method, such a series of models can convert a system COP into a change in fuel economy and CO_2 emissions from the hardware changes in an A/C system. The controls strategy changes in the menu will have to be measured with an A to B comparison on the chassis dynamometer test procedure described above. To do this, the manufacturer would test a vehicle with a baseline controls strategy compared with a modified more efficient strategy. Though EPA has not yet conducted a test program to test the feasibility of this concept, combining the results from the bench and dynamometer tests should give a quantitative assessment of the credits from an improved A/C system compared to a baseline system. Such an approach could be used in a manufacturer's engineering analysis submission, to demonstrate effectiveness of a technology (or technologies) in the absence of a of a baseline vehicle test.

The Alliance and others commented that the bench testing methodology is too complex and costly (and thus impractical) to employ as a compliance mechanism. The agencies tend to agree with this assessment. Due to the relative complexity (and expense) of a

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[p] According to the second law of thermodynamics, the COP of a real heat pump system is limited to the Carnot cycle efficiency, which is the ratio of the low Temperature to the difference between the high and low temperatures (in Kelvin).

bench test and model demonstration, it would be practical for a manufacturer to do this testing for only a small number of vehicle and A/C configurations in any given year. The EPA has met with a few manufacturers and also received comments regarding test vehicle selection, and they have informed EPA that on any single vehicle platform, the A/C systems usually share similar configurations. Most full line manufacturers only have a handful of vehicle platforms (in order to save on engineering and manufacturing costs). Therefore, this compliance demonstration and engineering analysis should only have to be conducted infrequently on a brand-new vehicle platform or A/C system design. AS described above, based on the limited number of platforms and the relative infrequency of platform redesigns, EPA expects that any manufacturer may ultimately only be required to do a compliance demonstration and engineering analysis of A/C credits for a given platform perhaps one or two times, depending on the number of unique A/C system designs used on the various models within that platform in order to generate credits.

One clarification that is being added to this final rule is to note that air conditioner efficiency is an "off-cycle" technology. It is thus appropriate for a manufacturer to employ the standard off-cycle credit approval process described in Section II.F and III,C of the preamble, as well as in the MYs 2012-2016 rule if the manufacturer believes it can demonstrate that a greater amount of credit is justified. Utilization of bench tests in combination with dynamometer tests and simulations (similar to the SAE IMAC study) would be an appropriate alternate method of demonstrating and quantifying technology credits (up to the maximum level of credits allowed for A/C efficiency). A manufacturer can choose this method even for technologies that are not currently included in the menu starting as early as model year 2012 (2017 for CAFE).

5.1.4 Air Conditioner System Costs

A/C system technologies include improved hoses, connectors and seals for leakage control. They also include improved compressors, expansion valves, heat exchangers and the control of these components for the purposes of improving tailpipe CO_2 emissions and fuel economy as a result of A/C use. The GHG and fuel economy effectiveness is unchanged from estimates used for 2016 model year vehicles in the 2012-2016 final rule.

In the MYs 2012-2016 rule, EPA estimated the direct manufacturing costs (DMC) of direct/leakage reduction A/C controls at $17 (2007$) and of indirect/efficiency improvement controls at $53 (2007$). These DMCs become $18 (2010$) and $55 (2010$), respectively, for this analysis. EPA continues to consider those DMCs to be applicable in the 2012MY and continues to consider the technologies to be on the flat portion of the learning curve. For this rule, the 2012-2016 rule technologies represent the reference case in terms of controls and costs. We have applied to those DMCs low complexity ICMs of 1.24 through 2018 then 1.19 thereafter to generate the indirect costs for this reference case. The resultant reference case costs are shown in Table 5-15.

New for this rule, and consistent with the proposal, are additional costs for indirect/efficiency improvement control as those 2012-2016 MY vintage systems penetrate to the entire fleet. In addition, as new costs are assumed which are associated with the alternative refrigerant—both the alternative refrigerant itself and the system changes to accommodate that refrigerant. For the first of these—indirect controls—the agencies have estimated the DMC at $15 (2010$) applicable in the 2017MY. The agencies consider this technology to be on the flat portion of the learning curve and have used a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. For the alternative refrigerant, the agencies have estimated a DMC of $67 (2010$) applicable in the 2016MY. The agencies consider this technology to be on the steep portion of the learning curve because it is only now starting to be used in a limited number of vehicles. For this technology, the agencies have used a low complexity ICM of 1.24 through 2022 then 1.19 thereafter. For the alternative refrigerant system costs (i.e., the hardware changes necessary to accommodate the alternative refrigerant), the agencies have estimated a DMC of $15 applicable in the 2016MY The agencies consider this technology to be on the flat portion of the learning curve and have used a low complexity ICM of 1.24 through 2018 then 1.19 thereafter. The resultant control case costs are shown in Table 5-16.

Note that these costs are expected to be incurred consistent with our estimated ramp up of manufacturer use of A/C credits. For example, the direct credit for low GWP refrigerant use is 13.8 g/mi in MYs 2017-2025, but we estimate that the average credit earned by manufacturers would be 5.5 g/mi on cars in MY 2018 and 5.8 g/mi on trucks in that MY. Table 5-13 shows the credits by MY as we estimate they will be used for both cars and truck. Table 5-14 then shows how we have used these estimated credits to scale A/C-related costs by MY for both cars and trucks. The percentages shown in Table 5-14 are included in the costs shown in Table 5-15 and Table 5-16.

The total A/C related costs are shown in Table 5-17.

Table 5-13 Projected Average Estimated Use of A/C Credits in g/mi

		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Car (g/mi)	Direct (Leakage) Credit if All R-134a AC	5.4	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
	Direct Credit for Low GWP AC	0.0	2.8	5.5	8.3	11.0	13.8	13.8	13.8	13.8	13.8
	Indirect Credit	4.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Total Credit	10.2	12.8	14.3	15.8	17.3	18.8	18.8	18.8	18.8	18.8
Truck (g/mi)	Direct (Leakage) Credit if All R-134a AC	6.6	7.0	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
	Direct Credit for Low GWP AC	0.0	0.0	5.8	10.3	13.8	17.2	17.2	17.2	17.2	17.2
	Indirect Credit	4.8	5.0	6.5	7.2	7.2	7.2	7.2	7.2	7.2	7.2

	Total Credit	11.5	12.0	17.5	20.6	22.5	24.4	24.4	24.4	24.4	24.4

Table 5-14 Scaling of A/C Costs to Estimated Use of Credits

		2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
2012-2016 Rule (reference case)											
CAR	Leakage Reduction	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%	5.4/6.3 =85%
	Low GWP Refrigerant & Hardware	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%	0.0/13.8 =0%
	Efficiency Improvements	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%	4.8/5.0 =97%
TRUCK	Leakage Reduction	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%	6.6/7.8 =85%
	Low GWP Refrigerant	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%	0.0/17.2 =0%
	Efficiency Improvements	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%	4.8/7.2 =47%
2017-2025 Rule(control case)											
CAR	Leakage Reduction		1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%
	Low GWP Refrigerant & Hardware		2.8/13.8 =20%	5.5/13.8 =40%	8.3/13.8 =60%	11.0/13.8 =80%	13.8/13.8 =100%	13.8/13.8 =100%	13.8/13.8 =100%	13.8/13.8 =100%	13.8/13.8 =100%
	Efficiency Improvements		1-97% =3%	1-97% =3%	1-97% =3%	1-97% =3%	1-97% =3%	1-97% =3%	1-97% =3%	1-97% =3%	1-97% =3%
TRUCK	Leakage Reduction		1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%	1-85% =15%
	Low GWP Refrigerant		0.0/17.2 =0%	5.8/17.2 =34%	10.3/17.2 =60%	13.8/17.2 =80%	17.2/17.2 =100%	17.2/17.2 =100%	17.2/17.2 =100%	17.2/17.2 =100%	17.2/17.2 =100%
	Efficiency Improvements		1-47% =53%	1-47% =53%	1-47% =53%	1-47% =53%	1-47% =53%	1-47% =53%	1-47% =53%	1-47% =53%	1-47% =53%

Table 5-15 Costs of A/C Controls in the Reference Case (2012-2016 Final Rule) (2010$)

Car/ Truck	Cost type	A/C Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
Car	DMC	Leakage reduction	$13	$13	$13	$13	$12	$12	$12	$12	$11
	DMC	Efficiency improvement	$46	$45	$44	$43	$42	$41	$41	$40	$39
	IC	Leakage reduction	$4	$4	$3	$3	$3	$3	$3	$3	$3
	IC	Efficiency improvement	$13	$13	$10	$10	$10	$10	$10	$10	$10
	TC	Leakage reduction	$17	$17	$16	$16	$15	$15	$15	$15	$14
	TC	Efficiency improvement	$59	$58	$54	$53	$52	$52	$51	$50	$49
Truck	DMC	Leakage reduction	$13	$13	$13	$13	$12	$12	$12	$12	$11
	DMC	Efficiency improvement	$32	$31	$31	$30	$29	$29	$28	$28	$27
	IC	Leakage reduction	$4	$4	$3	$3	$3	$3	$3	$3	$3
	IC	Efficiency improvement	$9	$9	$7	$7	$7	$7	$7	$7	$7
	TC	Leakage reduction	$17	$17	$16	$16	$15	$15	$15	$15	$14
	TC	Efficiency improvement	$41	$40	$38	$37	$36	$36	$35	$35	$34

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 5-16 Costs of A/C Controls in the Control Case (2017-2025 Rule) (2010$)

Car/ Truck	Cost type	A/C Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
Car	DMC	Leakage reduction	$2	$2	$2	$2	$2	$2	$2	$2	$2
	DMC	Low GWP refrigerant	$13	$22	$32	$34	$42	$41	$39	$38	$37
	DMC	Low GWP refrigerant hardware	$3	$6	$9	$11	$14	$13	$13	$13	$13
	DMC	Efficiency improvement	$1	$1	$1	$1	$1	$1	$1	$1	$1
	IC	Leakage reduction	$1	$1	$1	$1	$1	$1	$1	$1	$1
	IC	Low GWP refrigerant	$3	$6	$10	$13	$16	$16	$13	$13	$13
	IC	Low GWP refrigerant hardware	$1	$1	$2	$2	$3	$3	$3	$3	$3
	IC	Efficiency improvement	$0	$0	$0	$0	$0	$0	$0	$0	$0
	TC	Leakage reduction	$3	$3	$3	$3	$3	$3	$3	$3	$3
	TC	Low GWP refrigerant	$17	$28	$42	$47	$58	$57	$52	$51	$50
	TC	Low GWP refrigerant hardware	$4	$7	$10	$14	$17	$16	$16	$16	$16
	TC	Efficiency improvement	$2	$2	$2	$2	$2	$2	$2	$2	$2
Truck	DMC	Leakage reduction	$1	$2	$2	$2	$2	$2	$2	$2	$2
	DMC	Low GWP refrigerant	$0	$18	$32	$34	$42	$41	$39	$38	$37

	DMC	Low GWP refrigerant hardware	$0	$5	$9	$11	$14	$13	$13	$13	$13
	DMC	Efficiency improvement	$1	$11	$15	$15	$14	$14	$14	$13	$13
	IC	Leakage reduction	$0	$1	$1	$1	$1	$1	$1	$1	$1
	IC	Low GWP refrigerant	$0	$5	$10	$13	$16	$16	$13	$13	$13
	IC	Low GWP refrigerant hardware	$0	$1	$2	$2	$3	$3	$3	$3	$3
	IC	Efficiency improvement	$0	$3	$3	$3	$3	$3	$3	$3	$3
	TC	Leakage reduction	$1	$3	$3	$3	$3	$3	$3	$3	$3
	TC	Low GWP refrigerant	$0	$24	$42	$47	$58	$57	$52	$51	$50
	TC	Low GWP refrigerant hardware	$0	$6	$10	$14	$17	$16	$16	$16	$16
	TC	Efficiency improvement	$1	$14	$18	$18	$18	$17	$17	$17	$17

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table 5-17 Total Costs for A/C Control Used in This Final Rule (2010$)

Car/ Truck	Cost type	Case	2017	2018	2019	2020	2021	2022	2023	2024	2025
Car	TC	Reference	$76	$75	$70	$69	$68	$67	$66	$65	$64
	TC	Control	$25	$40	$57	$65	$79	$77	$72	$71	$69
	TC	Both	$101	$115	$127	$134	$147	$144	$138	$135	$133
Truck	TC	Reference	$58	$57	$54	$53	$52	$51	$50	$49	$49
	TC	Control	$2	$46	$73	$82	$95	$93	$88	$86	$84
	TC	Both	$60	$103	$127	$134	$147	$144	$138	$135	$133
Fleet	TC	Both	$86	$111	$127	$134	$147	$144	$138	$135	$133

TC=Total cost

The agencies received no public comments on A/C costs, though the EPA did have confidential meetings with alternative refrigerant suppliers. Due to the confidential nature of the information shared, the costs and supply discussions from these meetings are not relied upon to determine the costs in the tables above.

5.2 Off-Cycle Technologies and Credits

EPA employs a five-cycle test methodology to evaluate fuel economy for fuel economy labeling purposes. For GHG and CAFE compliance, EPA uses the established two-cycle (city, highway or correspondingly FTP, HFET) test methodology. EPA recognizes that there are technologies that provide real-world GHG benefits to consumers, but that the benefit of some of these technologies is not represented on the two-cycle test. Therefore, EPA is continuing the off-cycle credit program from the MYs 2012-2016 rule with some changes such as providing manufacturers with a list of pre-approved technologies for which EPA can quantify a default value that would apply unless the manufacturer demonstrates to EPA that a different value for its technology is appropriate. This list is similar to the menu driven approach described in the previous section on A/C efficiency credits. In meetings with vehicle manufacturers prior to the proposal, the EPA received comments that the regulatory process for generating off-cycle credits was too cumbersome to utilize frequently if at all, and that the burden of proof to demonstrate a small incremental improvement on top of a large tailpipe measurement was impractical. This is similar to the argument described above for quantifying air conditioner improvements. These same manufacturers believed that such a process could stifle innovation and fuel efficient technologies from penetrating into the vehicle fleet. EPA generally agrees with these comments, and proposed and is finalizing a menu with a number of technologies that the agency believes will show real-world CO_2 and fuel economy benefits which can be reasonably quantified a priori. The estimates of these credits were largely determined from research, analysis and simulations, rather from full vehicle testing, which would have been cost and time prohibitive. However, actual vehicle testing was used to either support or refine the credit estimates in cases where it was available.

In the proposal, the agencies requested comment on all aspects of the off-cycle credit menu technologies and derivations. EPA and NHTSA received a number of comments and, in addition, several stakeholders requested meetings and met with the agencies including Denso, Enhanced Protective Glass Automotive Association (EPGAA), ICCT and Honda.

Overall, there was general support for the menu based approach and the technologies included in the proposed list, but there were also suggestions to re-evaluate the definition of some of the technologies included in the menu, the calculation and/or test methods for determining the credits values, and recommendations to periodically re-evaluate the menu as technologies emerge or become pervasive.

In the proposed off-cycle credit menu, credit values were fixed for most of the technologies while others values were based on a step-function (e.g., x amount of credit for y amount of reduction or savings) on the off-cycle credit list. In response to the proposal, the agencies received comments requesting the use of a scalable credit value approach rather than a fixed values or step-function derived values for high efficiency exterior lighting, waste heat recovery (formerly termed "engine heat recovery"), solar panels (formerly termed "solar roof panels"), and active aerodynamics. After much evaluation of and in response to these comments, the agencies have revised the credit determination approaches for these technologies by allowing scalable off-cycle credit values derived from a specific technologies implementation affecting their relative reductions or savings. However, a by-product of moving to this calculation strategy is the deviation, in some cases, from the proposed methodology of subtracting a technology's 2-cycle test procedure benefits from the benefits determined on the 5-cycle test procedure as the agencies, in their evaluation, determine this approach was not easily or accurately to scalable. As a proxy, EPA employed a vehicle simulation tool, and applied varying load reduction values to determine benefits shown during 5-cycle testing, where applicable, to develop tables and/or curves to provide sound data properly scale credit values. This revised calculation approach is discussed in greater detail for each applicable technology in the following sections.

Another complication that arises from scaling, is that extremely small credit values can now be quantified. Although we are allowing scaling of the credits, we cannot accept a request or grant credit for any level of credit less than 0.05 g/mi CO2. As proposed and finalized, the agencies will be reporting CO2 values rounded to the nearest tenth of gram/mile, as a result, any reported values below 0.05 g/mi of CO2 would be rounded down to zero. Therefore, only credit values equal to 0.05 g/mi or greater will be accepted and approved for any credit requested as part of the off-cycle credit program (e.g., scalable or fixed; via the pre-defined technology list or alternate method approval process)..

Some commenters suggested that technologies should be added to the list such as high efficiency alternators (Alliance, Denso, VW, Porsche, Ford), electric cooling fans (Bosch), HVAC eco-modes, transmission cooler bypass valves (Ford), navigation systems (Garmin), engine block heaters (Honda) and an "integral" approach utilizing a combination of technologies (Global Automakers). Daimler commented that the agencies should provide "congestion mitigation credits based on crash avoidance technologies."

Conversely, some commenters were opposed to adding any technologies to the menu (CBD) and others suggested some of the proposed values should be re-evaluated (ICCT) or that the values should be based on real test data, not simulation modeling (NRDC).

In most cases, there was either insufficient supporting data, dependence on unique, manufacturer-specific designs or implementation, or dependence on driver interaction and usage that led to our decision not to include these technologies within the menu of off-cycle technologies. These comments are discussed in more detail in the Preamble Section II.F.

Finally, the agencies carefully assessed all of the comments and conducted additional analysis in response to the comments, as well as to support the agencies' ongoing work. The resulting adjustments to off-cycle credit menu values that are being finalized are detailed in the following sections.

In addition to comments about the individual technologies, the agencies received a number of comments on the proposed minimum penetration thresholds, the proposed cap on the amount of menu based off-cycle credit that can be applied, and suggestions to allow the proposed menu and credit values to be applied to MY2012-2016 vehicles. These comments, and EPA's response to them, are discussed in preamble sections II.F. and III.C.5.

5.2.1 Reducing or Offsetting Electrical Loads

The EPA test cycles do not require that all electrical components be turned on during testing. Headlights, for example, are always turned off during testing; including daytime running lights (DRLs). Turning the headlights on during normal driving will add an additional load on the vehicle's electrical system and will affect fuel economy. More efficient lighting, electrical systems or technologies that offset electrical loads will have a real world impact on fuel economy but are not captured in the EPA test cycles. Therefore, the EPA believes that technologies that reduce or offset electrical loads related to the operation of the vehicle or safety deserve consideration for off cycle credits.

To evaluate technologies that reduce or offset electrical loads, the EPA conducted an analysis of the reduction in emissions corresponding to a general reduction of electrical demand in a vehicle. Using EPA's vehicle simulation tool described in Chapter 2 of EPA's

RIA, the agency evaluated the change in fuel consumption for a 100W reduction in electrical load for a typically configured vehicle. The impact of this load reduction was modeled on both the combined FTP/Highway cycles (2-cycle), and over the 5-cycle drive tests. The results of this analysis form the basis for a consistent methodology that the EPA applied to several technologies to determine the appropriate off-cycle credits for those technologies. In the NPRM, a single conversion factor was proposed to convert Wattage to the CO_2 and fuel consumption benefit. For the final rule, the agencies have determined that this conversion should depend on the technology. Based on this determination, the solar energy capture and high efficiency exterior lighting credit are now calculated differently from the waste heat recovery credit. The method by which each technology converts and uses electrical energy is discussed below.

5.2.2 Waste Heat Recovery

The combustion process that powers most of today's vehicles results in a significant amount of exhaust heat. Most of this heat leaves the engine in the form of waste hot exhaust gasses which are expelled from the vehicle through the exhaust system, or through hot coolant which that transfers heat from the engine through the radiator to the atmosphere. Recapturing some portion of this wasted heat energy and using it to offset the electrical requirements of the vehicle will lead to improved fuel efficiency.

Regardless of the design of the heat recovery system, whether it is exhaust or coolant based, the EPA assumes that any recovered energy will be in the form of electricity and will be used to recharge the vehicle's battery (primarily for HEVs or PHEVs). This is consistent with currently proposed waste heat recovery system designs. The GHG and fuel economy benefit of generating a Watt of energy is estimated though a full vehicle simulation analysis.

For the vehicle simulation, EPA assumed that high-efficiency alternators will be prevalent in most vehicles within the MY2017-2025 timeframe of this rule; thus, the simulation includes a high-efficiency alternator. Figure 5-4 below shows a sample efficiency map of a high-efficiency alternator. Based on this map (used in the proposal for waste heat recovery), the global average alternator efficiency is 65%. For this final rule, in order to be consistent with the analysis conducted by Ricardo to inform the efficiency of powertrain and vehicle technologies,[39] EPA used a global efficiency of 70% (from high efficiency alternators) for use in its modeling calculations as presented below.

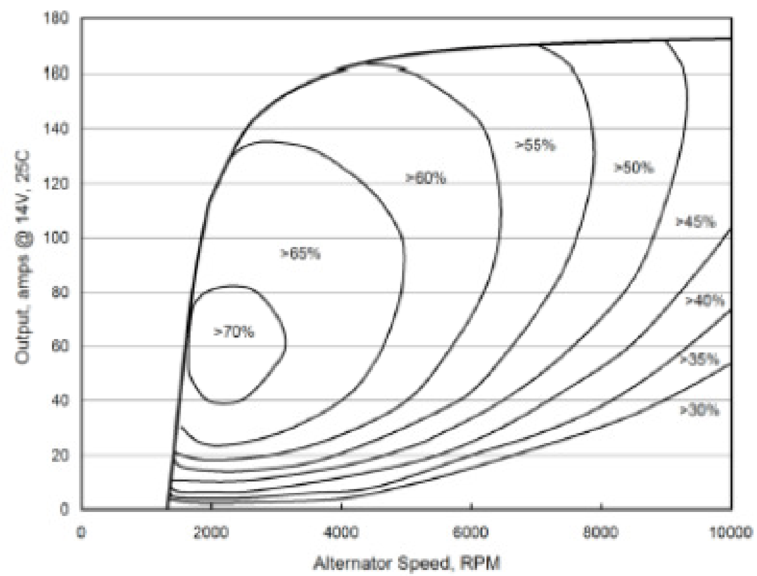


Figure 5-9: Alternator efficiency map (Delco-Remy, 2008[40])

Table 5-18 below shows the results of the revised simulation using 70% efficiency for four vehicle classes. Reducing the electrical load on a vehicle by 100W will result in an average of 2.5 g/mile reduction in CO_2 emissions over the course of a combined FTP/Highway test cycle, or 3.2 g/mile over a 5-cycle test. A 100W reduction in electrical load yields a reduction in required engine power of roughly 0.15 kW (=0.1 kW / 65%), or 1-2% over the FTP/HWFE test cycles.

Table 5-18: Simulated GHG reduction benefits of 100W reduction in electrical load over FTP/HW and 5-cycle tests

Driving Cycle	Electrical Load	Small Car [g/mile]	Mid-Size Car [g/mile]	Large Car [g/mile]	Pick-up Truck [g/mile]	Average* [g/mile]
FTP/Highway	100W Load Reduction	156.8	187.7	246.5	416.6	
	Base	154.2	185.5	244.1	413.9	
	2-Cycle Difference	2.5	2.2	2.4	2.7	2.5
5-Cycle	100W Load Reduction	217.8	256.9	331	544.5	
	Base	214.6	254.1	327.9	541.1	
	5-Cycle Difference	3.2	2.8	3.1	3.4	3.2
	5-Cycle/2-Cycle Difference	**0.7**	**0.6**	**0.6**	**0.7**	**0.7**

* based on a sales average

To determine the off-cycle benefit of certain 100W electrical load reduction technologies, the benefit of the technology on the FTP/Highway cycles (2-cycle test) is subtracted from the benefit of the technology on the 5-cycle test. This determines the actual benefit of the technology not realized in the 2-cycle test methodology and in this case is 3.2 g/mi minus 2.5 g/mi, or 0.7 g/mi.[q]

We received two comments on this approach. The International Council on Clean Transportation (ICCT) commented that they felt it is inappropriate to subtract 5-cycle benefits from 2-cycle benefits for waste heat as well as other technologies (discussed below). Instead, the ICCT suggested that the 2-cycle percentage benefits should be used for the load reduction estimate. The Alliance commented in support of the approach of subtracting the 2-cycle benefits from the 5-cycle benefits. However, they also wanted to have the technologies that use the load reduction estimate to be scalable rather than as a single value (i.e., 0.7 g/mi CO_2 credit per 100 watts reduced). Other commenters shared the desire for more scalable credits for this and other technologies. While these comments apply to all of the electrical load technologies, it is fitting to discuss them here first.

Regarding subtraction of the 2-cycle from the 5-cycle benefits, the ICCT did not feel the method of subtracting the 2-cycle benefits from the 5-cycle benefits was appropriate. Instead, they recommended we use the 2-cycle percentage benefits to estimate any electrical load reduction that does not occur on the test cycles. Supplemental comments from the Alliance identified the inherent contradiction of ICCT's assertions to have "credits properly reflect actual in-use reductions" while advocating for the use of 2-cycle testing, which typically has lower electrical loads than the 5-cycle tests and the real-world. The agencies agree with the supplemental comments from the Alliance and, therefore, we have decided not to subtract the 2-cycle benefits from the 5-cycle benefits to develop a base load reduction estimate and off-cycle credits.

We do agree with ICCT that utilizing the difference between 5-cycle and 2-cycle benefits for all of the off cycle technologies that affected electrical loads may not be appropriate. Based on this comment, we are only applying this methodology to waste heat recovery as this technology will have 2-cycle benefits. Accordingly, the other load reduction technologies, high efficiency exterior lighting and solar panels should have an alternate method of calculation (since they will not have 2-cycle benefits) which is described in greater detail in sections below.

We agree with the comments from the Alliance to allow scaling and are using the base load reduction estimate directly for calculating the waste heat recovery credit. Accordingly, we have developed the table and figure below that will allow for appropriate scaling of the credit based on the load reduced. Therefore, we are finalizing a scalable approach using the table and figure below based on these comments.

Table 5-19 Estimated electrical load reduction estimate and corresponding credit values.

[q] However, other technologies (for example, lighting and solar panels) providing benefits off-cycle that cannot be measured on either the 5-cycle test nor the 2-cycle test be used as the credits without subtracting a 2-cycle value. An example of this is provided later [WHERE?].

Electrical Load [W]	CO2 Credit [g/mile]
10	0.1
50	0.3
100	0.7
150	1.0

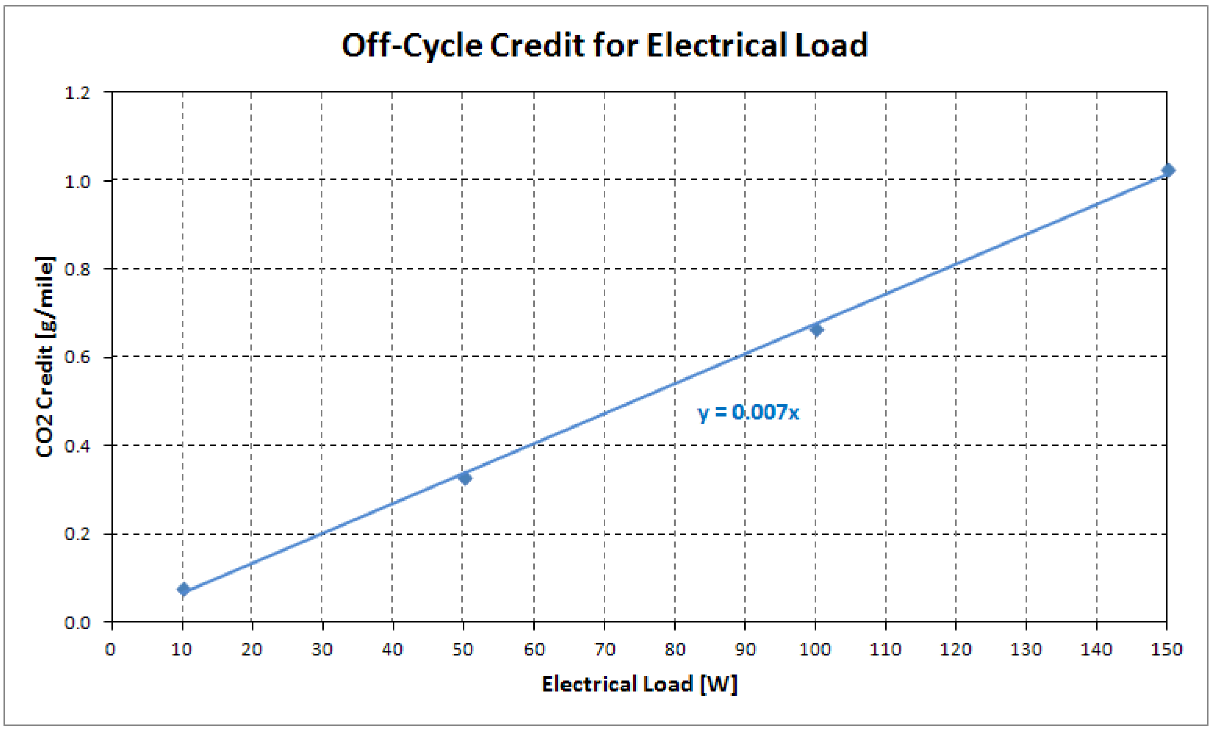


Figure 5-10 Graph of estimated electrical load reduction and CO2 credit (g/mile)

We received comments from Honda requesting clarification on whether the waste heat recovery value is the peak value or the average value over the test cycle. Honda recommended that it should be based on the average value over a 5-cycle test. We agree that this requires clarification and are clarifying the waste heat recovery credit is based on the average value over 5-cycle testing.

Honda also requested the definition for waste heat recovery to be expanded for conversion to mechanical and thermal energy in addition to "electrical energy." The conversion of waste heat to thermal energy is already covered elsewhere under the active engine and active transmission warm-up so we believe the additional inclusion of thermal energy conversion as part of waste heat recovery is not necessary. The conversion of waste heat to mechanical energy is more difficult to quantify since we do not have any data of these systems on current vehicle applications. Therefore we have not included these mechanical energy conversion systems on the table and we are finalizing the definition for waste heat recovery specifying the conversion to electrical energy only.

Finally, comments from Borg-Warner and the Motor Equipment Manufacturers Association (MEMA) mentioned that the term "engine heat recovery" was too narrowly defined or ambiguous regarding the type of applicable technology. Therefore, they recommended a more neutral approach and advocated for the term "waste heat recovery" currently used by the industry, academia, and the Department of Energy. We agree with these comments and have revised the terminology for this credit in both this section and in the regulatory text .

The revisions to the terminology and definition, and other clarifications are reflected in the definitions below under section 5.2.5.

5.2.3 High Efficiency Exterior Lights

The current EPA test procedures are performed with vehicle lights (notably, headlights including daytime running lamps (DRLs)) turned off. Because of this, improvement to the efficiency of a vehicle's headlights is not captured in the existing test procedures and is appropriately addressed through the off-cycle crediting scheme. Further, since a typical level of improvement can be quantified, it is appropriate to include this technology within the off cycle credit menu.

Similar to the waste heat recovery, EPA conducted full vehicle simulation to determine the impact of energy savings from high efficiency lights on fuel economy and CO_2 emissions. The methodology is identical to that described above with the exception that the 2-cycle results were not subtracted from 5-cycle test results (in response to ICCT's comments). Rather, the energy levels with and without the technology were compared directly on the 5-cycle simulation only. This results in a CO_2 reduction of 3.2g/mi per 100 Watt saved (or generated in the case of solar panels) as shown in Table 5-18 (in the NPRM, this value was 3.7 g/mi per 100 Watts).

As with residential light bulbs, the technology available for vehicle lighting has changed significantly in recent years. Vehicle manufacturers are commonly using advanced technology LEDs in taillights and offering new light producing technologies for headlights. If these technologies require less energy to operate, they will improve the overall fuel economy of the vehicle and will be eligible for an off-cycle credit.

For the proposal, we referenced Schoettle, et al.[41], which studied the effects of high-efficiency LED lighting. In the draft TSD, Table 5-19 provided a summary excerpted from that study of average lighting power requirements for both baseline and high efficiency lights for late-model vehicles and Table 5-20 provided usage rates.

We used these two tables to develop a simple activity-weighted average of the aforementioned categories which yielded an average nighttime power consumption (for the categories in question) of roughly 180W for a baseline vehicle and 120W for a vehicle with high efficiency lights as shown in the draft TSD that accompanied the proposal. This difference of 60W (180W-120w) was discounted to 30W since 50% of all VMT occurs at night based on MOVES activity data. Using this 30W and the base load reduction values of 3.7 g/mi CO2 benefit per 100 watts on the 5-Cycle test, we proposed a credit value of 1.1 g/mi (e.g., (30 watts/100 watts) x 3.7 g/mi).

We received several comments suggesting that the value shown in the table for high-efficiency low beams of 108.0 watts from the Schoettle et al. report (October 2008) was overstated. Three commenters, the Alliance, Volkswagen and Honda, suggested separate values for the low beam high efficiency lighting. The Alliance suggested a value of 52.4W using the baseline wattage of 112.4W for a savings of 60W. Volkswagen suggested a value of 54W and a baseline of 137W, based on an European application, for a savings of 83W. Lastly, Honda suggested a value of 66W also using the baseline wattage of 112.4W as well, based also on a European application, for a savings of 46.4W. Since this report is slightly older and these values are from actual vehicle applications, we agree with the commenters that these suggested values may be more representative of today's vehicles. Therefore, we used these numbers to revise our high-efficiency exterior light calculations. These high-efficiency and baseline low beam wattages represent a percentage savings of 53% (52.4/112.4), 61% (54/137) and 41% (66/112.4) respectively. Out of these, we used the most conservative saving estimate of 41%, which is much larger than the 4% savings we originally assumed. Therefore, we used 66W (41% of the 112.4W for baseline low beam lighting) for the high-efficiency low beam menu value based on the comments and supporting data.

The Alliance also commented that the brake/stop lamps and center high mounted stop lamp (CHMSL) lighting are enabled during the 2-cycle tests meaning that some of the real-world benefit would also be seen on the 2-cycle tests. Since stop/brake and CHMSL already have a very low usage rate, the benefit of high-efficiency lighting on these two lights would be minimal (and as explained above, would be rounded to zero). Therefore, these two lighting elements have been eliminated from the list.

Additional comments from the Alliance and Honda recommended that, rather than the bulk approach that we proposed, we allow scaling of the credit according to the lighting systems on the vehicles and that manufacturers be allowed to select individual lighting components from the list to receive credit. To address these comments, a different approach was required as the method above provides for a more absolute value based on a discrete number of components and values. In addition, the approach above uses a 2-cycle/5-cycle test comparison. Manufacturers currently do not operate lighting, with the exception of stop/brake lights and CHMSL, on the test cycles and, as a result, this approach would have required them to start enabling lighting during these test cycles.

For the lighting components used only at night, we used a night time VMT discount of 28.2%, to determine the credit for these components based on a more recent review of MOVES VMT data as shown in Table 5-20 below. The values in the table were determined by taking the total VMT distributed on a monthly basis and applying the sunrise and sunset times on the 15th day of each month over the VMT distribution to develop a relationship between VMT and the time of day on a monthly basis, and then taking the average of the monthly night time fraction.

Table 5-20 MOVES data showing fraction of VMT attributed solely to night time driving

month	Day VMT	Night VMT	Night Fraction
1	1,647,881	1,022,867	0.383
2	1,776,185	894,563	0.335
3	1,931,025	739,723	0.277
4	2,083,232	587,516	0.220
5	2,129,737	541,011	0.203
6	2,195,311	475,438	0.178
7	2,171,185	499,563	0.187
8	2,109,682	561,067	0.210
9	1,959,926	710,823	0.266
10	1,781,577	889,172	0.333
11	1,641,451	1,029,297	0.385
12	1,582,657	1,088,092	0.407
All	23,009,849	9,039,131	0.282

For the components used during day and night, this simply becomes 1.0, which implies there is no discounting based on night time only usage.

Therefore, we used the power demand estimates, with the revision to the low beam lighting element, along with the VMT fractions and developed individual lighting credits for each component on the high-efficiency exterior lighting list as shown in Table 5-21 below.

Table 5-21 Individual Credit Values for High Efficiency Exterior Lighting Components

Lighting Component	**Baseline**	**High Eff**	**Night Use Only %**	**Day & Night Use %**	g/mi CO2 Credit	**Savings %**
Low Beam*	112.4	***66***	91%	0%	0.38	52%
High Beam	127.8	68.8	9%	0%	0.05	46%
Parking/Position	14.8	3.3	100%	0%	0.10	78%
Turn Signal, front	53.6	13.8	0%	5%	0.06	74%
Side Marker, Front	9.6	3.4	100%	0%	0.06	65%
Tail	14.4	2.8	100%	0%	0.10	81%
Turn signal, rear	53.6	13.8	0%	5%	0.06	74%
Side Marker, rear	9.6	3.4	100%	0%	0.06	65%
License Plate	9.6	1	100%	0%	0.08	90%
Base electrical load redux	100	watts				
Fuel savings per 100W	3.2	g/mi	Nighttime VMT (MOVES Data):		28.2%	
Total Available Credit	1.0	g/mi				
**Value for high efficiency wattage changed based on comments and supporting data*						

Using this table, manufacturers may use all of the lighting components on this list and receive a maximum of 1.0 g/mi credit. Alternatively, as requested by comment, manufacturers may select individual lighting components from this list to determine the credits for high efficiency exterior lighting. To receive high efficiency exterior lighting credit using the pre-defined technology list, manufacturers may only use the lighting elements and the values shown in this table.

If a manufacturer has lighting elements that result in a higher benefit than shown on this table, the manufacturer *may* use these values under the alternate case-by-case approval process by performing according to the following formula below:

High Efficiency Exterior Lighting Credit =

$$\frac{(\text{Baseline lighting wattage} - \text{high efficiency lighting wattage}) \times \text{usage rate} \times \text{VMT fraction} \times 3.2\ \text{g/mi } CO_2}{100\ \text{watts}};$$

where usage rate is the percentage shown below for the applicable lighting component, the vehicle miles traveled (VMT) fraction is 28.2%, or 0.282, for lighting components used during night time only and 100%, or 1.0, for lighting components used during the daytime and night time. However, if a manufacturer has lighting elements that provide less benefit than shown on this table, these lighting components are not eligible for the high-efficiency exterior lighting credit. To implement this limitation, the agencies reserve the right to request a list of lighting elements from the manufacturer to support the amount of credit requested, regardless if it is via the pre-defined technology list or as part of the case-by-case approval process.

We received comments from Honda requesting a separate credit for replacing lighting relays as well.[42] Page 5 of that comment indicates that the implementation of all lighting relays produces a small total savings of 1.9W. Therefore, we do not believe lighting relays merit a separate credit due to the small amount of credit that would be generated. However, they can be included in an assessment of high efficiency exterior lighting credit under the alternate method approval process since this would create values other than that shown above in Table 5-21.

We also received considerable comment regarding the inclusion of daytime running lights (DRLs) on the list of high efficiency exterior lighting. The Agencies did not propose to include DRLs on the high efficiency exterior lighting list, and are adhering to that decision in the final rule. It is difficult to assign a power demand value to DRL since some manufacturers may choose to use dedicated DRLs while some manufacturers may choose to use the low beams as DRLs. In addition, some manufacturers may implement it on all their vehicles while some will choose to implement DRLs on a portion of vehicles (or not at all). The other primary reason for rejecting inclusion of DRL on the pre-approved menu technology list is that DRLs are currently disabled during the 2-cycle testing and, consequently, there is no basis for comparison to the 5-cycle test or real-world unless test procedures are modified to require DRL enablement during standardized test procedure. As a result, it is difficult to pinpoint a single strategy to assign power demand, assess fleet implementation rates, and account for it on the standardized test cycles to develop a single credit value. Therefore, we are not including DRLs in the list of lighting elements used to grant a high-efficiency exterior lighting credit on the technology list menu. However, as mentioned before, manufacturers may use the alternate case-by-case demonstration methods finalized in today's action to request off-cycle credit for DRLs.

Finally, LEDs used for decorative or accent lighting are not eligible for off-cycle credits under either the technology menu or through a case-by-case demonstration. This is because LEDs are properly classified as optional accessories or "features".

5.2.4 Solar Panels

Manufacturers are beginning to offer the option to put solar cells on the roof of a vehicle. The solar panel option on the new Toyota Prius is an example. The initial implementation of this idea has been limited to cabin ambient temperature control (this technology is covered under thermal/solar load control below), but manufacturers have raised the possibility of using roof top solar cells to charge PHEV and EV batteries and provide energy to operate the vehicle, increasing the vehicle's all-electric range. This electrical energy cannot be accounted for on the current EPA cycles – either the two cycle test or the five-cycle test. Only HEVs, PHEVs and EVs are eligible for this credit.

Using engineering judgment, the EPA estimated in the NPRM that vehicles with a solar roof would be parked in sunlight on average four hours a day, and that the solar panels would have an output of 50W. The EPA also assumed that the solar cells will produce 50% of their rated power of 50W (due to the solar angle, parking conditions, weather conditions, etc.) with a battery efficiency of 80%. A vehicle with this configuration could save up to 80 Wh/day of electrical energy. The EPA sought comments on these assumptions and requested more data to refine these numbers (See draft joint TSD section 5.2.1.3). EPA also noted the possibility of scaling the credit for certain solar roof panels. Id.

The ICCT commented that this credit was not appropriate and was not supported by actual data. However, in contrast, the Alliance comments stated that this level of credit was appropriate based on theoretical calculations and experimental data.

In addition, the Alliance recommended that 1) the credit should be scalable (e.g., (solar roof panel output in watts divided by 50 watts) times 3.0 grams/mile), 2) the credit should apply for solar panels in locations other than the roof, and 3) the credit should be available for other vehicles, not just PHEVs and EVs.

The comments from Guardian stated that solar roof panel technology is "rapidly evolving" to the point where the 50 watt threshold we proposed "will be quickly surpassed or [is] being surpassed." To address this, they also proposed that we use a simple, formula-based credit similar to the Alliance comments on scaling. Similar to the Alliance, Guardian recommended that this credit should not be limited to just "roof" panels if other locations can provide appropriate output and, therefore, the term "roof" should be removed to reflect this. Finally, Guardian suggested that we use standard test conditions (STC) from the photovoltaic industry to define how panel power is determined of 1000 watts per meter squared (W/m^2) direct solar irradiance and a panel temperature of 25 degrees Celsius.

First, we agree with the Alliance comments that we should scale solar panel credits. As the agencies stated in the draft joint TSD, "EPA will also consider scaling this credit for solar roof panels that provide more or less power than 50W." Second, the current definition for "solar roof panels" does not specify that the panels must be on the roof, although the term "roof" implies this. Therefore, we understand the potential for confusion and will change the term for this credit and the associated definition to "solar panels". However, since this term also creates some ambiguity, we will clarify that the term "solar panels" is limited to "horizontally-oriented, external solar panels with the potential for direct, uninhibited solar exposure." This prevents someone from installing solar panels in less effective locations (e.g., underneath the vehicle or in the vehicle passenger cabin) and claiming credit for solar roof panels. Lastly, the reason we limited this credit to HEVs, PHEVs and EVs is this is where we see the most benefit for this technology. It would not aid conventional vehicles since this would amount to "trickle" charging of the battery and, since hybrid vehicles have many methods and more substantial means of energy recovery, we did not see a need to expand this credit beyond HEVs, PHEVs and EVs. We do see a benefit for this technology on conventional vehicles when combined with active cabin ventilation, and these credits are already included on the menu.

We also agree with the comments from Guardian regarding revising the terminology, as discussed above, and defining the test conditions to determine the solar panel power output. We performed a cursory literature search and verified the conditions that Guardian stated, along with a specification for an air mass of 1.5 (AM1.5). As a result, we are including these metrics as well as the revised credit terminology in the definitions section. Also, as Guardian stated, the power output of 50 watts seems to have been surpassed and that solar panel outputs of up to 150 watts are possible. Therefore, we are revising the solar panel credit formula to allow for scaling to more efficient and larger panels.

Based on the comments from the Alliance and Guardian, and the agencies' own suggestion in the draft Joint TSD, we revisited the credits for solar panels to provide for proper scaling. Similar to high-efficiency exterior lighting discussed above, we needed to use a different approach since the method used for the proposed solar roof panel credit assigned was based on the credit scalar according to Table 5-22. This scalar represents an improvement in CO_2 emissions for every 100 W of electrical load reduced in vehicles equipped with conventional powertrains. Therefore it is inappropriate to use this scalar to represent an efficiency improvement from solar panels. For this final rule, we use some of the base assumptions in the proposal along with new information regarding methods for quantifying the energy from solar panels to improve the calculation methodology.

To properly scale the credit, we estimated the energy generated by the solar panel and stored in a P/H/EV battery. Then we used a number of vehicle simulation results from Ricardo to determine a gram per mile displaced by running a vehicle off of electric power (as in a battery). First, it is important to define the industry standard for rated solar panels, which is:

$$P_{panel} = \eta_{pv} * \Phi s_{ysw} * A$$

Where: $P_{\underline{panel}}$ is the rated panel power output_
η_{pv} is the Photovoltaic cell efficiency
Φs_{ysw} is the standard radiation flux (assumed to be 1000W/m^2) [r]
A is the Solar Panel Cell Area in m^2

Next, we calculate the amount of energy that is captured by the solar panel on a yearly basis and stored in the battery of the P/H/EV considering the following factors: the average solar energy across the United States on a daily basis, the battery/motor efficiency, the amount of time that the solar panel is exposed to the sun accounting for obstructed parking by structures, clouds and inclement weather, and the size and efficiency of the solar panel. The formula for this is as follows:

$$E_{panel} = \underline{E}_{avg} * Days/Year * \eta_{batt} * Exp_{solar} * \eta_{pv} * A$$

Where:

$\underline{E}_{avg}$ is the national average solar energy flux per day (approximately 4.159 $kWh/m^2/day$)[s], including the effects of weather, season, clouds etc

Days/Year is the number of days per year (365.25 days per year);

η_{batt} is the average battery/motor combined efficiency (assumed here to be 95% for battery, 92% for motor, and 98% for power electronic for a total of 86%)[t];

Exp_{solar} is the amount of solar exposure for the solar panel or "derate" factor,[u] assumed to be 79% and includes soiling and shading (e.g., trees, parking, buildings).

To determine the average solar energy per day of 4.159 $kWh/m^2/day$, we used the historical data from the National Renewable Energy Laboratory (NREL). Specifically, we used the State Average Insolation Values (2003-2005) Weighted by Region of Use Based on 2005 Electricity Use Patterns in $kWh/m^2/day$. We used all of the states except Alaska and Hawaii since this would tend to skew the data in a certain direction since these states tend to be at the extremes of solar exposure. The data is listed for several angles of incidence but we used the values for a horizontal panel since the solar panels on a vehicle do not automatically move to acquire an optimal angle for solar exposure. The values we used are shown below in Table 5-22.

[s] Estimated from http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/

[t] Consistent with the assumption in the proposal, we are assuming that the power from the solar cell will be stored in the battery for the most part. CITE TO PROPOSAL. A small portion can be used directly to power accessories or even the traction motor during normal vehicle operation (in which case, this factor is not required), but most vehicles spend most of their time parked. This analysis also assumes that the battery state of charge is sufficiently low to be able to accept additional energy.

[u] Estimated from http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/derate.cgi. In order to determine Exp_{solar} (derate), we used the following factors: shading = 0.85, soiling = 0.95 (default), system availability = 0.98 (default), and all other factors 1.0, as most of these factors relate to stationary applications. We assumed the suntracking factor of 1.0 since it would be already included in $\underline{E}_{avg}$.For the shading factor, we assume that any vehicle purchaser who is willing to pay a significant premium for a solar roof will preferentially park it in an area of high sunlight exposure.

Table 5-22 State Average Insolation Values (2003-2005) Weighted by Region of Use Based on 2005 Electricity Use Patterns in kWh/m^2/day for contiguous United States

State	Insolation Value (2003-05 for a flat panel)
Alabama	4.3
Arizona	5.6
Arkansas	4.3
California	4.9
Colorado	4.8
Connecticut	3.7
Delaware	3.9
District of Columbia	3.9
Florida	4.7
Georgia	4.3
Idaho	4.4
Illinois	3.9
Indiana	3.9
Iowa	4
Kansas	4.4
Kentucky	4
Louisiana	4.5
Maine	3.7
Maryland	3.9
Massachusetts	3.7
Michigan	3.7
Minnesota	3.7
Mississippi	4.4
Missouri	4.2
Montana	3.9
Nebraska	4.2
Nevada	5.4
New Hampshire	3.7
New Jersey	3.8
New Mexico	5.5
New York	3.8
North Carolina	4.2
North Dakota	3.7
Ohio	3.8
Oklahoma	4.5
Oregon	3.8
Pennsylvania	3.7
Rhode Island	3.8
South Carolina	4.3
South Dakota	4.1
Tennessee	4.2
Texas	4.6
Utah	4.6
Vermont	3.7
Virginia	4
Washington	3.6
West Virginia	3.8
Wisconsin	3.8
Wyoming	4.5

For our analysis, we used the average of the values across the contiguous states of 4.159 kWh/m^2/day to represent the broad spectrum of solar conditions across the United States. This is equivalent to a solar panel being exposed to the solar energy from the sun (also known as solar radiation or flux) of 1000 watts per square meter for 4.159 hours on a daily basis over the course of a year.

Substituting in the values above, we get:

$$E_{panel} = 4.159 \text{ kWh/m}^2\text{/day} * 365.25 \text{ days/year} * 0.86 * 0.79 * \eta_{pv} * A; \text{ or}$$
$$E_{panel} = 1030 \text{ kWh/m}^2\text{/Year} * \eta_{pv} * A$$

Next, we convert the energy from the panel to a gram per mile of CO_2 equivalent to determine the credit. In order to do this, we estimate the amount of tractive energy (energy to drive the wheels in kWh) and the associated CO_2 emissions for different subclasses of parallel hybrid (P2) vehicles. Comparing the energy generated at the battery with the amount of energy (and emissions) on the P2 hybrid vehicles, we estimate the amount of energy and hence emissions that are displaced by the solar panels.

The following tables show the 2-cycle average emissions and tactive energy based on full vehicle simulations and energy analysis of the hybrid vehicles as modeled by Ricardo (see Chapter 3 of the joint TSD for a description of the Ricardo work):

Table 5-23 CO2 Emissions from Each Vehicle Type

Driving Cycle	Small-Size Car	Mid-Size Car	Large-Size Car	Pick-up Truck
FTP (CO2 g/mi)	125.44	137.54	178.13	267.95
Highway (CO2 g/mi)	150.75	148.96	192.51	306.30
Combined (CO2 g/mi)	135.69	142.45	184.33	283.95

Table 5-24 Vehicle Travel Distance per Energy applied at Wheel

Traveled Mile per Energy applied at Wheel [mi/kWh]	Small-Size Car	Mid-Size Car	Large-Size Car	Pick-up Truck
FTP	5.7461	4.6861	3.8528	2.6663
Highway	5.5348	5.1317	4.0623	2.6553
Combined	5.6510	4.8867	3.9470	2.6613

Table 5-25 CO_2 Emissions per Energy applied at Wheel

CO2 per Energy applied at Wheel [g/kWh]	Small-Size Car	Mid-Size Car	Large-Size Car	Pick-up Truck
FTP	720.76	644.52	686.29	714.45
Highway	834.37	764.42	782.03	813.32
Combined	766.78	696.12	727.54	755.69

The sales weighted average CO_2 emissions is 745.8 g/kWh. This is using the sales and VMT schedules consistent with the rest of this rule. If we combine the emissions per unit energy with the annual energy generated from a typical panel along with an assumption of 15,000 miles traveled per year for an average vehicle[v], we get:

> Amount of CO_2 reduced by Panel = $\underline{E}_{panel}$ * 745.8 g/kWh * η_{batt} / 15000 mi/year; or
> Amount of CO_2 reduced by Panel = 43.85 g/mi * η_{pv} * A

By rated panel power relationship (defined above), but rewritten in the form:

$$P_{panel} / (1000 W/m^2) = \eta_{pv} * A$$

we get a scalable credit such that:

> Solar Panel Credit, C_{solar} = 0.04385 g/mi/W * P_{panel}

This equation is a function of only the rated power of the panel. These are standard specifications for solar panels and are provided by the panel manufacturers.

Therefore, for a 100 Watt rated panel, the credit would be 4.4 g/mi. This value is (per the public comments) now scalable to the solar cell.

As an illustrative example, the 2012 Toyota Prius solar panel is currently used for active ventilation[w] (equivalent to 2.1g/mi credit). However, if the solar panel were to be used to charge the battery it would get a higher credit: In the Prius, the approximate specifications for the solar panel are an efficiency rating of 16.5% (0.165) and an area of 0.405 m^2 thus having a rating of 67 Watts.[x] This would qualify for a credit of 2.9 g/mi CO_2.

This value of solar panel credit is comparable to the 2.1 g/mi credit from the active ventilation. However, the active ventilation is not required all year round (the remainder of the power generated being wasted). In an effort to encourage more solar use on P/H/EV vehicles, and to more accurately characterize the year-round potential benefits for use of the solar technology on vehicles, the agencies are finalizing a credit scheme that will allow benefits for active ventilation as well as for electrical generation. This was not included in the proposal and is new to the final rule as a result of the Agencies' effort to make this credit scalable.

[v] Consistent (though simplified) with assumptions made elsewhere in this rule
[w] http://global.kyocera.com/reliability/file02.html
[x] http://techon.nikkeibp.co.jp/english/NEWS_EN/20090519/170318/: Area is 36*.15*.075 = 0.405m^2, efficiency is 16.5%.

There are three scenarios to consider regarding the interaction between solar panels and active cabin ventilation: 1) using the solar panel solely for the purpose of charging the battery, 2) using the solar panel to only power the active cabin ventilation system, and 3) using the solar panel to charge the battery and power the active cabin ventilation. The first two scenarios are simpler and more straightforward so we will discuss them first together. The third scenario is more complicated due to power splitting.

If the solar panel is being used solely to charge the battery, the solar panel credit alone will be granted and the equation above can be used to determine the amount of solar panel credit. If the solar panel is being used solely to power the active cabin ventilation system, only the active cabin ventilation credit (see section 5.2.13 below) will be available.

If the solar panel is being used to both power the active cabin ventilation system and to charge the battery, the manufacturer may get credit for some combination of the solar panel and active cabin ventilation system credit. However, the manufacturer would be required to account for the amount of power required for the active cabin ventilation system, then calculate the applicable solar roof panel power for battery charging and subtracting the power for active cabin ventilation. Note that using the calculation below, a manufacturer could not get more credit than accounting for the solar panel and active cabin ventilation credits separately.

To account for the wattage that would be devoted for the active cabin ventilation, we use the equation above for the panel power and the wattage needed for fans used for active cabin ventilation. Based on information from Delphi, the power used to operate the fan motor used in active cabin ventilation is typically 19 Watts. In order to calculate the amount of the rated panel power that would generate the 19 W from the ideal solar flux of 1000 W/m^2, we first estimated the fraction of the average sunlight in US, which would be used to generate the required power.

$$f_{sun} = E_{avg} / n_{hr,day} / \Phi s_{ysw}$$

where:

f_{sun} is a fraction of the average sunlight in US (dimensionless);
$n_{hr,day}$ is an average daytime hours per day (assumed to be 12 hours/day).

After substituting appropriate values in this equation, we get 0.347 for f_{sun}. Using this value, we get the amount of the rated panel power that would generate the fan power from the ideal solar flux of 1000 W/m^2 is

$$P_{solar/vent} = P_{vent} / f_{sun}$$

Where:

$P_{solar/vent}$ is the amount of equivalent rated panel power that would generate power for the vent P_{vent}

P_{vent} is the amount of power required to run the low speed ventilation fan in the dashboard (assuming there is a route for the heat to escape the car). For this credit calculation, the value of 19 W must be used.

With the value of f_{sun}, $P_{solar/vent}$ turns out to be 54.8 W (using the fixed value of 19W for the fan). Then, the remaining solar panel credit for battery charging is calculated as follows.

$$C_{solar/vent} = 0.04385 \text{ g/mi/W} * (P_{panel} - P_{solar/vent} / 3)$$

Where:

$C_{solar/vent}$ is the solar panel credit available for battery charging after the ventilation fan power has been dissipated.

Note that P_{vent} is divided by 3 to account for the assumption that the active ventilation is used only 4 months a year on average. This amount would be subtracted from the solar panel credit menu value for full battery charging. Substituting, the partial credit equation becomes:

$$C_{solar/vent} = 0.04385 \text{ g/mi/W} * (P_{panel} - P_{vent} / (3*0.347))$$

Due to the inherent uncertainties in some of the assumptions, and for the sake of simplicity, we are setting the constant in the parentheses (3*0.347) to unity. Therefore the equation becomes simply:

$$C_{solar/vent} = 0.04385 \text{ g/mi/W} * (P_{panel} - P_{vent})$$

Using the Prius example to illustrate this, if the Prius used the solar panel to operate the active cabin ventilation system fan motor and to charge the battery, the Prius could receive 2.1 g/mi for active cabin ventilation and additional 2.1 g/mi solar panel credit attributable to battery charging. This 4.2 g/mi credit is higher than if the solar panels were used for electricity generation alone (2.9 g/mi). This credit recognizes that the agencies are now providing an incentive to use that additional power that might have been wasted in a beneficial manner, reducing GHG emissions and using less fuel.

In summary, we are finalizing the credits for solar panels using the revised values, allowing them to be scaled according to solar panel output, and allowing for combining the credit with the active ventilation credits where the solar panels are used for both purposes. The agencies are revising the terminology and definition for solar panel credits as discussed above. In addition, as proposed, the solar panel credit is only available for HEV, PHEV, EVs, and FCEVs (fuel cell), and is not eligible for incentive multipliers.

5.2.5 Definitions for Electrical Load Offsetting and Reduction Technologies

Waste heat recovery is a system that captures heat that would otherwise be lost through the engine, exhaust system, radiator or other sources and converting that heat to electrical energy that is used to meet the electrical requirements of the vehicle or used to augment other load reduction technologies (e.g., cabin warming, active engine/transmission warm-up strategies). The amount of energy recovered is based on the average value over 5-cycle testing.

High efficiency exterior lighting means a lighting technology that, when installed on the vehicle, is expected to reduce the total electrical demand of the exterior lighting system when compared to conventional lighting systems. To be eligible for this credit the high efficiency lighting must be installed on one or more of the following lighting components: low beam, high beam, parking/position, front and rear turn signals, front and rear side markers, taillights, backup/reverse lights, and/or license plate lighting.

Solar roof panels means the installation of horizontally-oriented, external solar panels with direct solar exposure, uninhibited by portions of the or the entire vehicle, on an electric, fuel cell electric, hybrid electric or a plug-in hybrid electric vehicle such that the solar energy is used to provide energy to the electric drive system of the vehicle by charging the battery or directly powering essential vehicle systems (e.g., cabin heating or cooling/ventilation), or providing power to the electric motor. The rated power of the solar roof panels used to determine the credit value must be determined under the standard test conditions of 1000 watts per meter squared direct solar irradiance at a panel temperature of 25 degrees Celsius +/- 2 degrees Celsius with an air mass of 1.5 spectrum (AM1.5).

5.2.6 Active Aerodynamic Improvements

The aerodynamics of a vehicle play an important role in determining fuel economy. Improving the aerodynamics of a vehicle reduces drag forces that the engine must overcome to propel the vehicle, resulting in lower fuel consumption. The aerodynamic efficiency of a vehicle is usually captured in a coast down test that is used to determine the dynamometer parameters used during both the two-cycle and five-cycle tests. This section discusses active aerodynamic technologies that are activated only at certain speeds to improve aerodynamic efficiency while preserving other vehicle attributes or functions. Active aerodynamic features can change the aerodynamics of the vehicle according to how the vehicle is operating, and the benefit of these vehicle attributes may not be fully captured during the EPA test cycles.

Two examples of active aerodynamic technologies are active grill shutters and active ride height control. Active grill shutters close off the area behind the front grill so that air does not pass into the engine compartment when additional cooling is not required by the engine. Nearly all vehicles allow air to pass through the front grill of the vehicle to flow over the radiator and into the engine compartment. This flow of air is important to prevent overheating of the engine (and for proper functioning of the A/C system), but it creates a significant drag on the vehicle and is not always necessary. Thus, active grill shutters reduce the drag of the vehicle, reduce CO_2 emissions, and improve fuel economy. When additional cooling is needed by the engine, the shutters open until the engine is sufficiently cooled.

Active ride height control uses the chassis and suspension components, such as hydraulic shock absorbers, to lower the height of the vehicle, thus reducing ground clearance, typically at higher vehicle speeds. This lowers the relative amount of air traveling under the vehicle while maintaining the amount of air around and over the vehicle. This reduces drag on the vehicle requiring less power to maintain the same speed, and consequently reducing fuel consumption.

As proposed, EPA is limiting credits to active aerodynamic systems only (not passive). The reason for this is that passive systems are too difficult to define and isolate as a technology. For example, the aerodynamic drag on the vehicle is highly dependent on the vehicle shape, and the vehicle shape is (in turn) highly dependent on the design characteristics for that brand and model. EPA believes that it would be inappropriate to grant off-cycle credits for vehicle aesthetic and design qualities that are passive and fundamentally inherent to the vehicle. Thus, passive aerodynamic systems are not an off-cycle menu technology, and also could not be a candidate for off-cycle credits under the case-by-case demonstration procedures.

To evaluate active aerodynamic technologies that reduce aerodynamic drag, the EPA conducted an analysis of the reduction in emissions corresponding to a general reduction of aerodynamic drag on a vehicle. Using EPA's full vehicle simulation tool described in EPA's RIA Chapter 2, the agency evaluated the change in fuel consumption for increasing reductions in aerodynamic drag for a typically configured vehicle. The results of this analysis form the basis for a consistent methodology that the EPA applied to technologies that provide active aerodynamic improvements.

Vehicle aerodynamic properties impact both the combined FTP/Highway and 5-cycle tests. However, these impacts are larger at higher speeds and have a larger impact on the 5-cycle tests. By their nature of being "active" technologies, EPA understands that active aerodynamic technologies will not be in use at all times. While deployment strategies for different active aerodynamic technologies will undoubtedly vary by individual technology, the impact of these technologies will mostly be realized at high speeds. Since aerodynamic loading is highest at higher speeds, EPA expects that active aerodynamic technologies will generally be in use at high speeds, and that the 5-cycle tests will capture the additional real world benefits not quantifiable with the FTP/Highway test cycles due to the higher speed in the US06 cycle. Active aero may also depend on weather conditions. For example, active aerodynamics may operate less in hot weather when air cooling is required to exchange heat at the condenser. Also, active grill shutters may need to stay open during snowy conditions in order to prevent them from freezing shut (potentially causing component failure). In fact, the MOVES data indicates that only 68% VMT occurs between 40 °F and 80 °F.

Using EPA's full vehicle simulation tools, the impact of reducing aerodynamic drag was simulated on both the combined FTP/Highway cycles and the 5-cycle drive tests. To determine the fuel savings per amount of aerodynamic drag reduction, the fuel savings on the FTP/Highway test cycle was subtracted from the fuel savings on the 5-cycle tests. This is consistent with the approach taken for other technologies. Then, using the MOVES data, the vehicle simulation results were adjusted for the temperature effects on active grill shutter operations. Table 5-26 shows the results of the vehicle simulation. Also, Figure 5-11 represents this GHG reduction metrics in a graphical form. These results assume that the active aerodynamics affects the coefficient of drag only, which is currently assumed to be constant over a wide range of vehicle operating speed. However, if the coefficient of aerodynamic drag is assumed to be vehicle speed dependent, then a different relationship could result.

Table 5-26 Simulated Maximum GHG Reduction Benefits of Active Aerodynamic Improvements

Reduction in Aerodynamic Drag (C_d)	Car Reduction in Emissions (g/mile)	Truck Reduction in Emissions (g/mile)
1%	0.2	0.3
2%	0.4	0.6
3%	0.6	1.0
4%	0.8	1.3
5%	0.9	1.6
10%	1.9	3.2

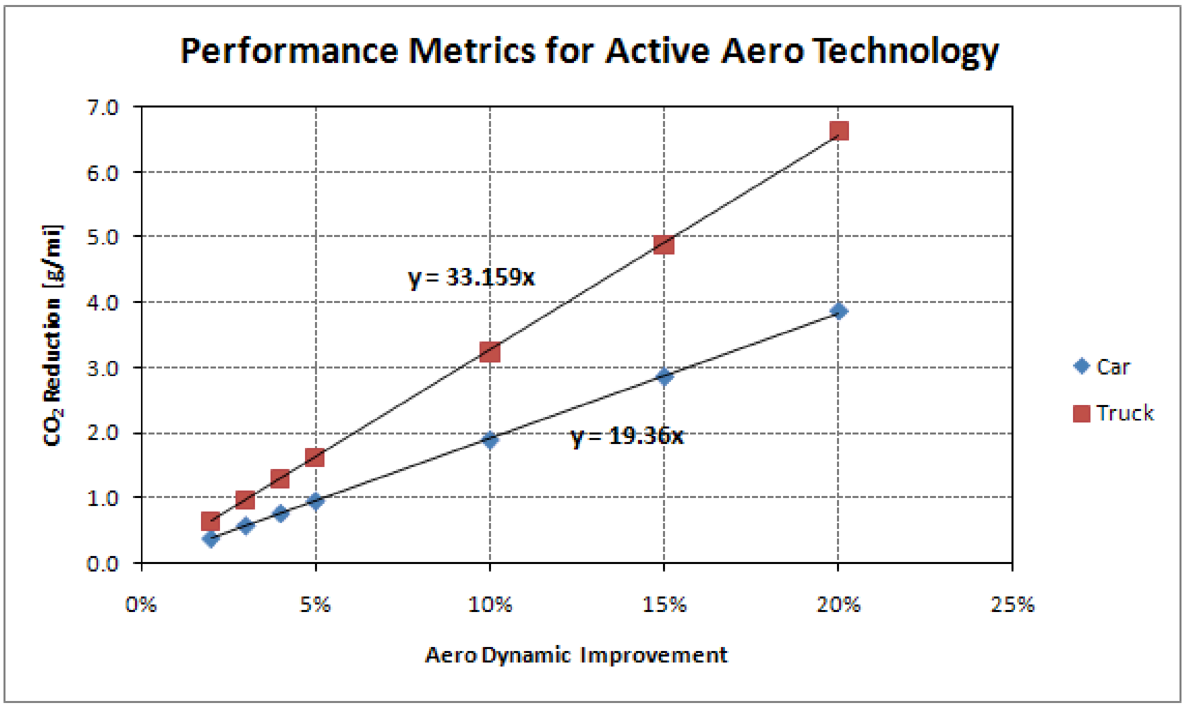


Figure 5-11 Simulated GHG Reduction Benefits of Active Aerodynamic Improvements

We are scaling the credit for active aerodynamics using Table 5-26 and Figure 5-11shown above. A manufacturer would simply determine the aerodynamic benefit of their active technology on a percent basis and find the corresponding CO_2 value in grams per mile off using the data points in the table.

5.2.7 Definition for Active Aerodynamic Improvements

Active aerodynamic improvements are technologies that are automatically activated under certain conditions to improve aerodynamic efficiency (e.g., lowering of the coefficient of drag or C_d using SAE J2881, while preserving other vehicle attributes or functions).

5.2.8 Advanced Load Reductions

The final category of off-cycle credits includes technologies that reduce engine loads by using advanced vehicle controls. These technologies range from enabling the vehicle to turn off the engine at idle, to reducing cabin temperature while a vehicle is parked and thus reducing A/C loading when the vehicle is restarted. Because the benefit of these technologies is not fully captured on the combined two cycle tests, and the real-world benefits can be reliably but conservatively calculated EPA has evaluated each technology and developed automatic off-cycle credits for each technology individually.

5.2.8.1 Engine Idle Start-Stop

Engine **idle** start-stop technologies enable a vehicle to turn off the engine when the vehicle comes to a rest, and then quickly restart the engine when the driver applies pressure to the accelerator pedal. The benefit of this system is that it largely eliminates fuel consumption at idle. The EPA FTP (city) test does contain short periods of idle, but not as much idle as is often encountered in real world driving. HEV and PHEVs can also idle-off and are thus eligible for this credit. EVs and FCVs do not have engines and thus are not eligible for this credit.

As stated in the proposed Joint TSD, based on a MOVES estimate that 13.5% of all driving (in terms of vehicle hours operating) nationwide is at idle, and compared to a 9% idle rate for the combined (two-cycle) test, idle-off could theoretically approach an extra 50% of the existing benefit seen on the FTP/HWFE test. Vehicle simulation data was used to quantify the amount of fuel consumed in idle conditions over the FTP and HFET test across a range of vehicle classes. For each vehicle class reviewed, a FTP-HFET combined fuel consumption was calculated and compared to total fuel consumption during the combined test. The ratio of idle fuel to total fuel represents a maximum theoretical fuel consumption, and hence GHG emissions, that could be reduced by eliminating idling[y]. Table 5-27 shows this below:

[y] Note that aggressive fuel cutoff upon vehicle decelerations are technically possible and could increase the total amount of avoided “idle” fuel consumption; at the same time, the idle-off enable conditions might reduce the total idle avoidance. Given the accuracy level of this methodology, EPA assumes these caveats to cancel each other out.

	Standard Car	Large Car	Large MPV	Full size Truck
Total FTP fuel consumption (g)	1044	1276	1412	1868
FTP fuel consumed at idle (g)	68	71	69	97
Total HWFE fuel consumption (g)	675	862	970	1240
HWFE fuel consumed at idle (g)	0.0	0.0	0.0	0.0
FTP-HWFE combined fuel consumption (g)	878	1090	1213	1585
FTP-HWFE combined fuel consumed at idle (g)	37	39	38	53
potential % GHG reduction benefit	**4.2%**	**3.6%**	**3.1%**	**3.4%**
% FTP idle time	16%	16%	16%	16%
% HWFE idle time	0%	0%	0%	0%
FTP-HWFE combined % idle time	9%	9%	9%	9%
Real-world % idle time (via MOVES)	13.5%	13.5%	13.5%	13.5%
Real-world % GHG reduction benefit	**6.3%**	**5.3%**	**4.6%**	**5.0%**
Off-cycle GHG benefit	**2.1%**	**1.7%**	**1.5%**	**1.6%**
Assumed GHG for advanced vehicle (g/mi)	165	235	255	365
Off-cycle GHG benefit	**3.4**	**4.1**	**3.9**	**6.0**

Table 5-27: Calculations Used for Off-Cycle Credit for Engine Idle Start-Stop Technologies

Based on the data in Table 5-27 above, EPA suggested that engine idle start-stop technology is theoretically capable of providing 3.8 g/mi credit for passenger vehicles and up to 6.0 g/mi for trucks. However, cold and hot ambient conditions will prevent idle-off in all cases. Based on MOVES data of VMT as a function of temperature (see Table 5-28 below), the percentage of nationwide VMT driven above a 45 °F ambient temperature is approximately 75%. Therefore, EPA and NHTSA proposed 75% of the theoretical savings above will be appropriate for an idle off credit; equating to 2.9 g/mi for passenger vehicles and 4.5 g/mi for trucks.

The comments from ICCT were critical of the underlying assumptions used to determine the amount of credit in two respects : 1) the idle rate assumed for the 2-cycle tests and 2) application of the real-world idle percentage to only the off-cycle credit value, not the underlying idle time used to determine the amount of the credit.

First, the commenter stated that the16% idle rate for the 2-cycle tests solely contributed by the FTP and listed in the TSD should actually be 19.5% in total, with 19% of the idle contributed by the FTP test and 0.5% contributed by the HWY test. Thus, when applying the FTP/HWY weighting of 55%/45%, this produces a weighted idle rate of 10.7%, not 9% used in the TSD.

Second, the commenter stated that we only applied the real-world idle percentage to scale the engine idle start-stop credit to the credit value, not to the underlying idle time used to determine the credit. This comment has technical merit. The agencies therefore we used the MOVES model to estimate that 13.5% of VMT was during idling, providing an opportunity for engine idle start-stop. Further, we assumed the engine would be running 25% of the time due to cold temperatures, leaving 75% of the real world VMT for stop start. Using vehicle simulation with the 13.5% real-world, idle-off time assumption, we estimated a potential benefit of 3.8 g/mi for cars and 6.0 g/mi for trucks and applied the real-world factor of 75%, resulting in a proposed credit of 2.9 g/mi for cars and 4.5 g/mi for trucks. Thus, the commenter's assertion was that the 75% real world factor should have been applied to the real world idle off time of 13.5%, yielding a true real-world idle off time of 10.1% (e.g., 13.5% times 75%). As a result, according to the commenter, there is no benefit to grant an applicable credit for engine idle start-stop.

We reviewed these comments thoroughly and agree that some of ICCT's comments have merit. In particular, the comments regarding the 10.7% idle rate for the 2-cycle test and the application of real-world factoring were appropriate. However, we disagree with ICCT regarding the real-world idle time and the lack of benefits for granting engine idle start-stop credits. Thus, we have revised the approach for determining engine idle start-stop credit as described below taking into account the issues highlighted by ICCT.

For the 10.7% 2-cycle idle rate, when we consider the amount of time to reach proper operating engine temperature, a small portion of the FTP was eliminated. Our in-house test data showed that the average time to reach 90% maximum engine coolant was on average 324 seconds, and due to this, eliminating the first two idle periods of the FTP. As a result, the idle rate we used for the 2-cycle test was 10.0% instead of the 10.7% suggested by the commenter.

Next we reviewed the estimates of the amount of idle time in the real world. We reviewed the analysis for the estimate of the real-world percent idle time in MOVES and, since new information has been added to the MOVES model since the NPRM, this number has increased slightly to 13.76% from the previous estimate of 13.5%. To validate this number, we reviewed other data and studies to see how it compares. In the Supplemental FTP (SFTP) studies conducted in the 1990's, there was a very large vehicle driving activity study conducted with instrumented vehicles (EPA 420-R-93-007, "Federal Test Procedure Review Project: Preliminary Technical Report, May 1993). The study revealed that the real-world percent idle rate (by time) was 22% and it is not certain how much driving patterns have changed since then. Therefore, we looked at more recent data, noting that , in 2003, EPA conducted another instrumented vehicle study in Kansas City. This study was much more limited in scope than the 3 cities study used in the SFTP as each of the vehicles was only instrumented for one day in Kansas City and the data from Kansas City was only collected for three seasons (fall/winter/spring). This study found that the percent idle time was 17.7%. Together, these two studies give evidence that idle rates in the U.S. could be higher than the 13.76% estimated from MOVES, and is probably higher than the 10.7% on the city/highway test procedure. For the final rule, we are applying the more recent MOVES estimate of 13.76%, which we believe is a conservative estimate. As new data are collected, EPA will continue to review idle rates to assess whether future adjustments in the credit values are warranted.

Since operating conditions, such as cabin heating and cooling, can greatly affect engine idle start-stop operation, we have re-evaluated the assumptions that were used in the proposal for the percentage of vehicle operation in various ambient temperature conditions that were used to estimate the percentage of vehicle operation that engine idle start-stop is enabled. Based on a review of MOVES data shown in Table 5-28 below, we found that VMT as a function of temperature is as follows: 1) 68.75% of VMT occurs between 40 deg F and 80 deg F (mid-range), 21.95% of VMT occurs below 40 deg F (cold range), and 9.69% of VMT occurs above 80 deg F (hot range).

Table 5-28 MOVES data of vehicle miles traveled (VMT) as a function of ambient temperature.

VMT	tempAvg	Fraction	Temp Range VMT Fraction
1181.656796	-25	0.00000157	
4400.79767	-20	0.00000585	
12905.217	-15	0.00001714	
40874.20742	-10	0.00005429	
174939.1854	-5	0.00023235	
762497.0884	0	0.00101274	
1915732.576	5	0.00254446	
4924729.91	10	0.00654097	
12353230.63	15	0.01640743	0.21958689
23259876.93	20	0.03089353	(< 40 deg F)
31418211.75	25	0.04172934	
41033016.47	30	0.05449962	
49426375.28	35	0.06564760	
55404781.78	40	0.07358805	
60396251.48	45	0.08021767	
63018086.25	50	0.08369996	
68380740.42	55	0.09082259	
73176481.47	60	0.09719224	0.68343503
72473451.14	65	0.09625848	(> 40 deg F, < 80 deg F)
67073984.17	70	0.08908697	
54637578.9	75	0.07256906	
39382139.05	80	0.05230695	
24182451.73	85	0.03211888	
7635253.418	90	0.01014106	
1203687.536	95	0.00159873	0.09697809
593360.565	100	0.00078810	(>80 deg F)
18352.30991	105	0.00002438	
752904571.9	TotalVMT	1.00000000	

We also reviewed data from the Kansas City Study and note that it had a nearly identical VMT-temperature distribution. Therefore, using this temperature distribution we assumed: 1) all the mid-temperature range is available for engine-off/stop-start operation since inhibiting factors (heater and A/C usage) are typically low in this range; 2) all the hot temperature range requires A/C operation and would prevent engine-off/stop-start and, consequently, none of this range is eligible for stop-start (note: it is possible that this is a conservative estimate as smart A/C controls, potential cooling storage, and electric compressors can allow engine to idle off for some hot idles while A/C is demanded); and 3) there are several factors that are important to consider in the cold temperature range such as average starting temperature, number of cold engine starts, time to reach sufficient engine coolant temperature, and the average trip length. Additional information was reviewed to refine the assumptions in the cold temperature range.

EPA also reviewed data from the Supplemental Federal Test Procedure (SFTP) study, the EPA's MOVES model, EPA testing, and other sources to attempt to refine the estimates of idle time in the cold ambient temperature range by looking at two key aspects: 1) the percentage of time when the engine is cold and trip time is less than 5 minutes; and 2) the percentage of time in the field that extended idle would occur to support cabin heating demands.

For the percentage of time when the engine is cold and trip time is less than 5 minutes, the SFTP Study showed that 49% of the time, the vehicle was running with engine temperatures less than 180 degrees F, which would potentially make this portion of operation unavailable for engine-off/stop-start because of the need to support cabin heating demands. However, EPA test data showed that the average time to reach 90% of maximum engine coolant is 324 seconds, which would eliminate only the first two idles in the FTP and, in addition, would mean only trip lengths shorter than 324 seconds are ineligible for engine-off/start-stop operation. Based on an estimate from MOVES data, 25% of the trips had a trip time less than 5 minutes which would not achieve full warm-up and are ineligible for engine-off/start-stop operation.

For the percentage of time in the field that extended idle would occur due to cabin heating, based on an estimate from MOVES data, a majority of the starts (95%) have idle times less than 5 minutes meaning that only 5% of the starts experience extended idle and are not eligible for engine-off/stop-start operation.

Based on this information, we revised the cold temperature range to reflect the portion of VMT that is not eligible for engine-off/stop-start operation by adding up the portions ineligible for engine-off/start-stop operation. The estimated amount of time in the real world when vehicles are not warmed up but idle time is greater than 5 minutes is 49% based on the SFTP study, multiplied by 25% based on MOVES, and equaling 12.25%, is the value used for the a-term in the equation below. The amount of time in the real world that is extended idle of greater than 5 minutes based on MOVES activity data is 5% of the 22% VMT in the cold range, or 1.1%, which is not eligible for engine-off/start-stop operation, and is the value used for the b-term in the equation below. We did consider that the upper limit of 40 deg. F for the cold temperature range was too low. However, it is possible that the upper range of 80 deg. F for mid-temperature range could be higher since they are highly dependent on the relationship between ambient temperature and humidity, and perceived passenger comfort. Therefore, we did not change the upper range of 40 deg. F of the cold regime since these factors balance each other.

Therefore, we revised our estimate of real-world % idle time by scaling it using these values and the following equation:

Adjusted real-world % idle time =

Real-world % idle time x (0.6875 [mid- temperature range] + 0.2195x [1-(a+b)] [cold temperature range])

Real-world % idle time x (0.6875 + 0.2195 x [1 - (0.1225 + 0.011)]

Real-world % idle time x (0.6875 + 0.19) =

Real-world % idle time x (0.8775) =

13.76 x 0.8775 = 12.07%

The above calculation assumes that the engine is warm after approximately 5 minutes in cold weather. It also assumes that engine-off/start-stop operation occurs during these conditions, even if heat is demanded by the passengers. For HEVs and PHEVs, this is a reasonable assumption, as today's HEVs usually have a mechanism for idling off the engine during cold temperatures. ICCT commented that this should not be applicable to all stop-start systems. The agencies agree that for the calculation to be applicable to 12 Volt stop-start systems, the vehicle should have some technology to continue to deliver heat to the cabin even if the engine is not running. This can be done in a number of ways including an electric heater circulation pump, secondary loops with heat reservoirs, or some other method of maintaining heat transfer from the coolant. For this reason, the agencies are assuming that future stop-start systems will include such technologies. In this final rule, the agencies have removed the electric heater circulation pump from the table as proposed (and discussed further in the next section). The manufacturer wishing to receive the full stop-start credit must attest that the vehicle includes some technology to allow the engine to idle off while the cabin heat is demanded. For those systems who do not include this technology, the real world idle time calculation is modified by subtracting the credit previously proposed for electric heater circulation pump of 1.0 g/mi for cars and 1.5 g/mi for trucks, and is reflected in the credit values discussed below.

Below are the details of our model simulations using these values and recalculating the stop-start, off-cycle credit. The off-cycle credit was calculated using EPA's in-house vehicle simulation tool, known as ALPHA (Advanced Light-Duty Powertrain and Hybrid Analysis Tool). The credit was calculated for cars and trucks, separately. Vehicle simulations were conducted using ALPHA for small, medium, large cars and pick-up trucks. The simulations were run only for FTP and Highway cycles with a baseline engine. First, the start-stop was deactivated for the vehicle simulations. Vehicle speed trace and fuel flow simulation results during the FTPcycle are shown in Figure 5-12 and Figure 5-13, respectively, for a small-size car. Also, the vehicle speed trace and fuel flow during Highway cycle are shown in Figure 5-14 and Figure 5-15, respectively.

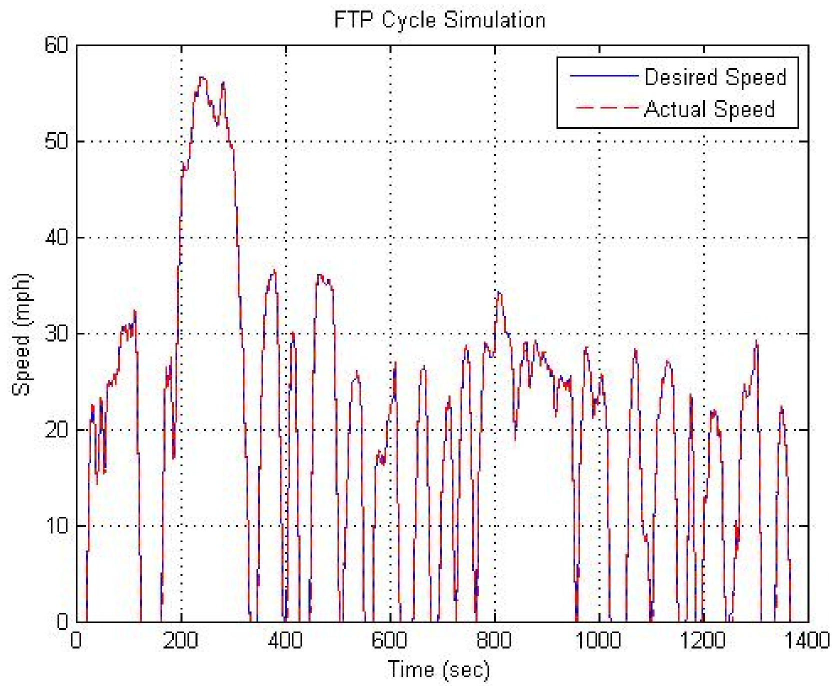


Figure 5-12 Vehicle Speed Trace during FTP Cycle

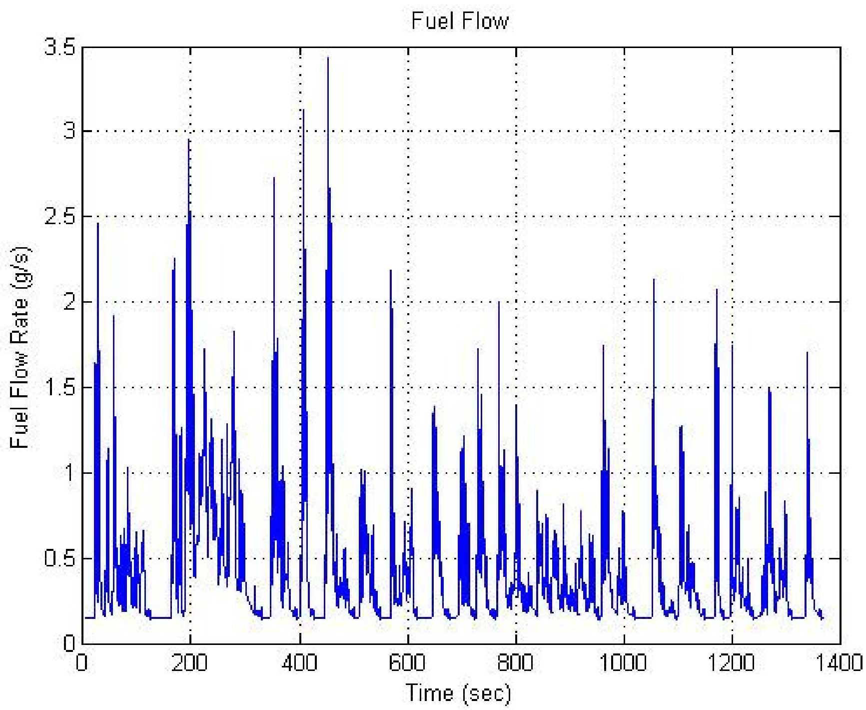


Figure 5-13 Fuel Flow Trace during FTP Cycle without Start-Stop

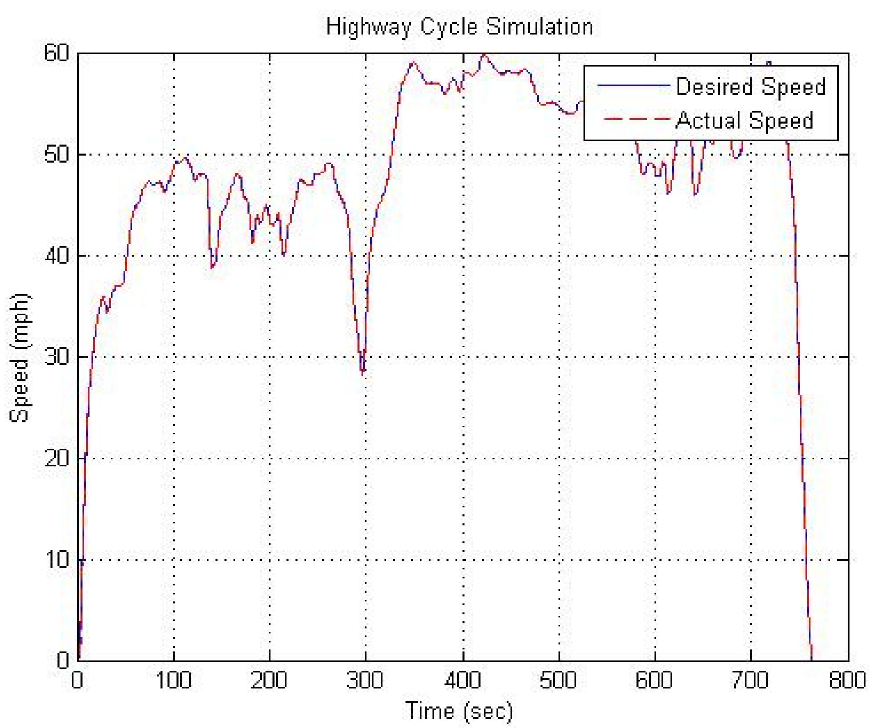


Figure 5-14 Vehicle Speed Trace during Highway Cycle

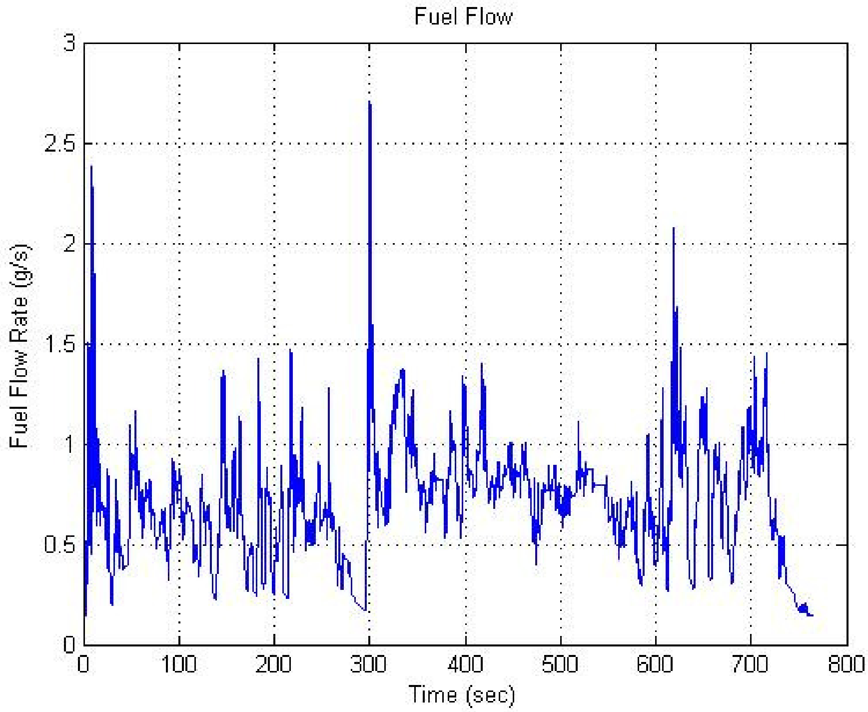


Figure 5-15 Fuel Flow Trace during Highway Cycle without Start-Stop

Next, the start-stop was activated during the vehicle simulations. It must be noted that the start-stop control algorithm was written such that the engine was not turned off during idle for the first 300 seconds of FTP cycle to allow the engine to warm-up. Figure 5-16 and Figure 5-17 show fuel flow traces during FTP and Highway cycles, respectively, for a small-size car with the start-stop activated.

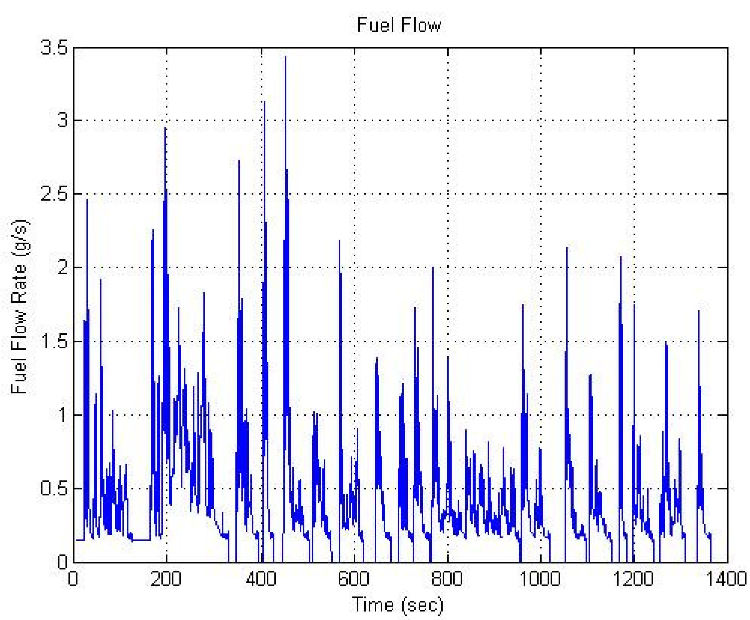


Figure 5-16 Fuel Flow Trace during FTP Cycle with Start-Stop

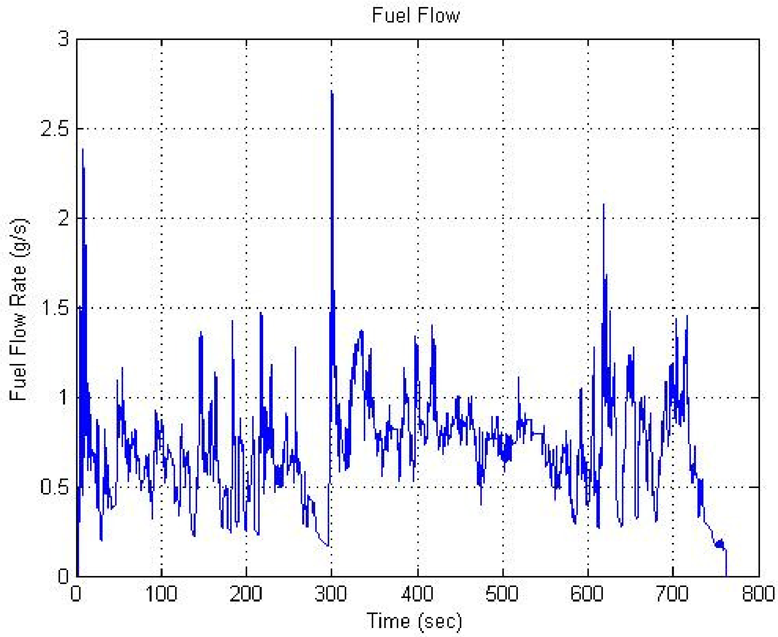


Figure 5-17 Fuel Flow Trace during Highway Cycle with Start-Stop

The simulation results are shown in Table 5-29 and Table 5-30 below.

Table 5-29 Vehicle Simulation Results for Start-Stop in [MPG]

Driving Cycle	Start-Stop	Small-Size Car	Mid-Size Car	Large-Size Car	Pick-up Truck
FTP	Off	36.91	26.39	21.28	14.38
	On	39.52	28.82	22.95	15.33
	Improve	2.61	2.42	1.67	0.95
Highway	Off	52.83	43.93	32.34	20.44
	On	52.93	44.04	32.42	20.48
	Improve	0.10	0.12	0.07	0.04
Combined	Off	44.08	34.28	26.26	17.11
	On	45.56	35.67	27.21	17.65
	Improve	1.48	1.38	0.95	0.54

Table 5-30 Vehicle Simulation Results for Start-Stop in [CO2 g/mile]

Driving Cycle	Start-Stop	Small-Size Car	Mid-Size Car	Large-Size Car	Pick-up Truck
FTP	Off	240.8	336.7	417.7	617.8
	On	224.9	308.4	387.3	579.6

	Improve	15.9	28.3	30.4	38.3
Highway	Off	168.2	202.3	274.8	434.7
	On	167.9	201.8	274.2	434.0
	Improve	0.3	0.5	0.6	0.8
Combined	Off	208.1	276.2	353.4	535.4
	On	199.2	260.4	336.4	514.0
	Improve	8.9	15.8	17.0	21.4

It is evident from these results that stop start has an effectiveness of about 4-5%. The percentage of time the engine is at idle for the FTP/Highway cycles and real world are 10% and 13.76% (MOVES analysis), respectively; allowing for the previously mentioned cold-start warmup. In these calculations, the agencies determined that all of the 10% idle time in FTP/Highway cycles is eligible for engine stop. However, for real world conditions, the agencies determined a reduced engine idle time is available for engine stop; specifically 87.75%[z] of the real world idle time of 13.76%. Using these values, the agencies concluded eligible engine off fractional values to be 10% for the FTP/HWFET test cycles and 12.07% for real-world conditions. Table 5-31 shows these calculations.

Table 5-31 Percentages of Idle eligible for Engine Off

Cycle	Idle Fraction	Percentage of Idle eligible for Engine-Off	Idle Fraction eligible for Engine-Off
FTP/HWFET	10.00%	100.00%	10.00%
Real-World	13.76%	87.75%	12.07%

Applying the idle fraction eligible for engine off values shown in Table 5-29 to the FTP/Highway combined cycles simulation values shown in Table 5-32, the agencies calculated the following start-stop credit values for each vehicle segment shown in Table 5-30.

Table 5-32 Start-Stop Credit for Each Vehicle Segment

Start-Stop Credit	Small-Size Car	Mid-Size Car	Large-Size Car	Full Size Truck
CO2 [g/mile]	1.8	3.3	3.5	4.4

The impact of Stop Start is generally dependent on engine displacement because larger engines generally have higher friction and pumping losses than smaller displacement engines at idle, and therefore have high CO_2 emissions and higher idle fuel consumption. The differences in the credits that are available to each segment are based on the different engine displacements typically used in each vehicle segment.

[z] This is due to temperature effects. Separate analysis was given earlier.

Credits for cars and trucks are obtained by sales-weighted averaging the car credits for model years 2017 to 2025, in Table 5-31. Note that sales-weighted averaging was used between large-size car, which typically has similar engine displacements as smaller trucks, and full size truck to determine the truck credit.[aa]

Table 5-33 Start-Stop Credits for 2017 to 2025

Year		2017	2018	2019	2020	2021	2022	2023	2024	2025
Credit	Car	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	Truck	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4

Based on Table 5-33, the start-stop credits are 2.5 g/mile for cars and 4.4 g/mile for trucks. These are values for vehicles equipped with idle-off cabin heat technologies. For vehicles unequipped with such technologies, the credits are reduced to 1.5 g/mi for cars and 2.9 g/mi for trucks. These are the credit values that EPA is finalizing for use in the final off-cycle credit menu.

5.2.8.2 Electric Heater Circulation Pump

Conventional vehicles use engine coolant circulated by the engine's water pump to provide heat to the cabin during operation in cold ambient conditions. Since the coolant is only circulated when the engine is running, very little heat is available to the cabin occupants if the engine is stopped during idle in vehicles equipped with stop-start. Stop-start equipped vehicles generally disable the feature during cold ambient temperatures to ensure cabin heat is always available. However, stop-start operation can be expanded to much colder ambient if a means of continuing to circulate coolant during idle stop is employed. An electric heater circulation pump takes the place of the engine's water pump to continue circulating hot coolant through the heater core when the engine is stopped during a stop-start event. Most HEVs, and PHEVs are currently equipped with this technology; however, the more simple 12 Volt Stop start systems may not be. Therefore, by definition of this technology's function, only vehicles equipped with stop-start technology, HEVs, and PHEVs are eligible for this credit.

Because the engine does not generate any more heat when it is shut off during idle, the amount of heat available to be moved to the cabin is limited by the thermal mass of the engine. The heater core acts like a radiator to remove heat from the engine and deliver it to the cabin. After some period of time, depending on engine mass, ambient temperature, and desired cabin temperature, the coolant temperature would drop to a level where comfort would not be maintained and the engine could cool off to a point where cold start features

[aa] Many of the assumptions made for the analysis were "conservative", others were "central". In this example, an average vehicle (or high sales class) was selected on which the analysis was conducted. In this case, a smaller vehicle may presumably be deserving of fewer credits whereas a larger vehicle may be deserving of more. Where the estimates are central, it would obviously be inappropriate for the agencies to grant greater credit for the larger vehicles since this value is already balanced by the smaller vehicles in the fleet. The agency will take these matters into consideration when case by case applications are submitted for technologies that are modifications to the ones listed on the menu.

would be needed (which increase fuel consumption). The stop-start control system would turn the engine back on before either of these conditions is reached. The coolant circulation pump is electrically powered and therefore uses some energy when in use.

EPA evaluated the effectiveness of this system using the same approach that was used for start stop technology. Based on MOVES data, we assumed the percentage of nationwide VMT below 45 °F is 25% and that vehicles with start stop systems will have to keep the engine running for cabin heat if the ambient temperature is less than 45 °F, unless the vehicle also has an electric heater circulation system. Therefore, we assumed a vehicle with both systems could utilize the start stop technology 25% more of the time. However, while reviewing our calculations for engine idle start-stop, we determined that there may be conditions where engine idle start-stop may be enabled without the use of an electric heater circulation pump or designs that can enable engine idle start-stop without the use of an electric heater circulation pump. For example, Honda commented that they were planning to implement such a system that would "to maintain all heating functions for more than 1 minute" when ambient conditions are as low as 30 deg F without the use of an electric heater recirculation pump.

Therefore, we are eliminating the separate credit for electric heater circulation pump and including the benefits of an electric heater circulation pump, or similar systems as implied by Honda, within the credit for engine idle start-stop. Given the interaction and synergies between the electric heater circulation pump and engine idle start-stop, we believe this is an appropriate decision. For more information on how electric heater circulation pump has been incorporated, see the discussion on engine idle start-stop above.

Finally, the Alliance and Honda commented that we revise our definition and terminology for this vehicle. The Alliance pointed out that the main purpose is to maintain cabin heating and "occupant thermal comfort" without using the conventional heater. Therefore, this credit should be renamed to reflect this goal and purpose. Similarly, Honda pointed out, as mentioned above, that they are planning on implementing a system that can accomplish this without the use of an electric heater circulation pump. As a result, the definition should be expanded to include any system that can maintain cabin heating and occupant thermal comfort, not just an electric heater recirculation pump.

5.2.8.3 Active Transmission Warm-Up

When a vehicle is started and operated at cold ambient temperatures, there is additional drag on drivetrain components due to cold lubricants becoming more viscous which increases fuel consumption and GHG emissions. This effect is more pronounced at colder temperatures and diminishes as the vehicle warms up. Components affected by this additional drag include the engine, torque converter, transmission, transfer case, differential, bearings and seals. Some components, such as the transmission, can take a long time to warm to operating temperature. Automakers sometimes delay the application of very effective fuel-saving measures such as torque converter lockup in order to help the transmission reach operating temperature more quickly.

Active Transmission warm-up uses waste heat from a vehicle's exhaust system to warm the transmission oil to operating temperature quickly using a heat exchanger in the exhaust system. This heat exchanger loop must have a means of being selectable, so that the transmission fluid is not overheated under hot operating conditions. In cold temperatures, the exhaust heat warms the transmission fluid much more quickly than if the vehicle relies on passive heating alone. Other methods of heating the fluid can be implemented using electric heat for example, but these are not included in this analysis because of the additional energy consumption that would likely eliminate most of the benefit. This technology could also be used for other driveline fluids such as axle and differential lubricant on rear-wheel-drive vehicles or even engine oil, but only transmission fluid warming is considered here.

There is a lot of variability in which components are affected by cold temperatures and for how long due to the type of vehicle and how it is operated. Active transmission warm-up applied to a conventional front-wheel-drive vehicle will warm the transmission, torque converter, and differential lubricants because in most cases these components share the same lubricant. On a rear-wheel-drive vehicle such as a truck, active transmission warm-up would only affect the transmission and torque converter. The rear axle and differential lubricant, and the transfer case and front axle and differential lubricants in a four-wheel-drive vehicle would not be heated. Additionally, a vehicle operated under a heavy load will tend to warm these lubricants more quickly with or without active heating.

Using Ricardo modeling data and environmental data from EPA's MOVES model, EPA calculated the estimated benefit of active transmission warm-up. The Ricardo data indicates that there is a potential to improve GHG emissions by 7% at 20 °F if the vehicle is fully warm. EPA assumed that given that this technology only affects the transmission (and differential on a FWD vehicle) and that the technology does take some time to warm the transmission fluid, one third of this benefit would be available, or 2.3%. EPA then assumed the benefit would decay in a linear fashion to 0% at 72 °F. This simple relationship is provided in Figure 5-18 below.

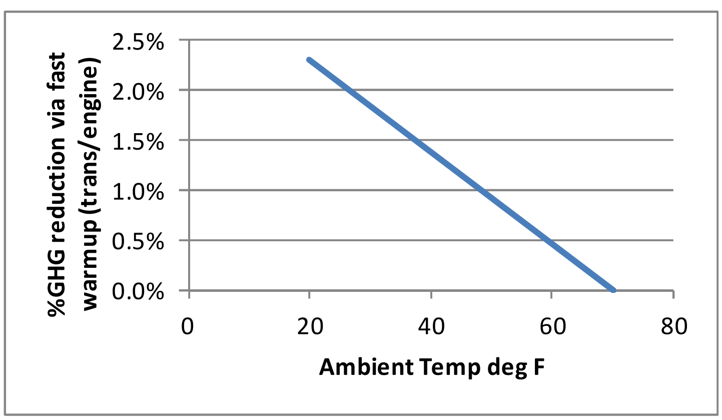


Figure 5-18 Relationship showing linear decay of GHG improvement as a function of ambient temperature.

Using MOVES data, EPA then calculated a nationwide VMT -weighted average ambient temperature for all light duty vehicles. Based on the distribution data shown in

Figure 5-18, the weighted average temperature was calculated at 58 °F and was assumed uniform for all vehicle classes. Combined with the relationship assumed in Figure 5-19, this weighted average temperature corresponds to an average benefit due to active transmission warm-up of 0.58% of baseline emissions.

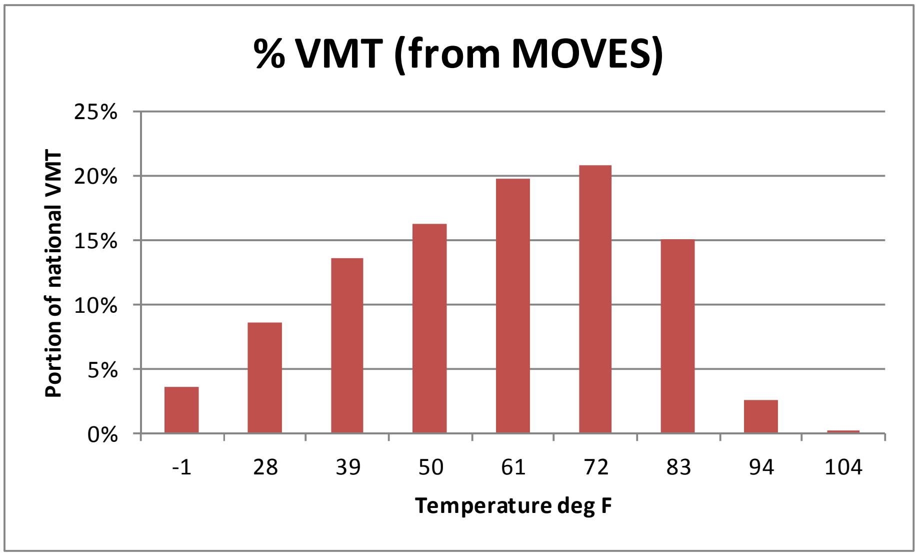


Figure 5-19 Distribution of national VMT by ambient temperature

Finally, when this 0.58% reduction is applied to baseline emissions for various vehicle class (as per the Ricardo-simulated 2010 baseline vehicles) the available credits, by vehicle class, are calculated and shown in Table 5-34.

Table 5-34 Available credits (g/mi) based on fuel economy and CO2 benefits by vehicle class

Vehicle Class	FTP (City) FE 70F	FTP (City) CO2 70F	Benefit g/mi
Small Car	39.8	223	1.3
Midsize Car	30.0	296	1.7
Large Car	23.8	373	2.2
Large Truck	16.2	549	3.2

Using EPA's sales schedules (see TSD Chapter 1, 1.3.3, Tables 1-13 and 1-14) and VMT's (see 5.2.8.1, Table 5-28 above) for the small car, midsize car, and large car vehicle classes, we get average sales-weighted credit values of 1.5 grams/mi for cars, and a non-sales weighted 3.2 grams/mi for trucks as trucks were not disaggregated by class. No benefit is assumed during the FTP, so nothing is subtracted from this result. EPA believes an off-cycle benefit of 1.5 and 3.2 grams/mile are possible using active transmission warm-up for cars and trucks, respectively.

In their comments to the NPRM, the Alliance supported the credit value of 1.8 grams/mile for active transmission warm-up but recommended that the definition be broadened to account for other methods of warm-up besides exhaust heat such as a secondary coolant loop. This sentiment for an expanded definition was also expressed by Volkswagen. Although we feel that waste heat from the exhaust system is one method, we are not opposed to other methods that provide similar performance such as coolant loops or direct heating elements that, albeit more costly, may prove to be more effective. Therefore, we agree with the commenters that the definition can be expanded and will reflect this change in the definitions section below.

The comments from Chrysler advocated for specific car and truck credits for active transmission warm-up similar to other advanced load reduction strategies, such as engine idle start stop and electric heater circulation pump. Based on these comments, we expanded the range of vehicle classes/categories above and agree with the commenter that there is a clear performance difference between active transmission warm-up systems on cars versus trucks. Therefore, as mentioned above, we are adopting the specific car-truck credit values of 1.5 grams/mi and 3.2 grams/mile, respectively, for active transmission warm-up.

Finally, Honda's comments requested clarification on systems that use a singular heat exchanging loop, rather than separate loops as we proposed, for active transmission and, as discussed below in the next section, engine warm-up. Honda indicated that all of their systems use a single heat exchanging loop for the transmission and engine, and, thus, would potentially be eligible for an additive credit of 3.6 g/mi CO_2, based on our NPRM credit values. It is uncertain if a single heat exchanging loop would be as effective as two separate loops for the transmission and engine, and ultimately eligible for a combined credit (e.g., under our revised credit values, a total of 3.0 g/mi CO_2 for cars and 6.4 grams/mi CO_2 for trucks). The agencies currently do not have foundational data to support the effectiveness of a single heat exchanging loop to increase the cold start fluid warming rate for both an engine and transmission under various ambient temperature conditions.

Therefore, the agencies will not grant additive, default credit values for active transmission and engine warm-up to systems using a single heat exchanging loop. Rather, a manufacturer employing such a design will be able to initiate a credit request for such a system would be made via the demonstration methods for technologies not on the defined technology list. At a minimum, the request would need to demonstrate the performance of the active transmission/engine warm-up for a single heat exchanging loop versus dedicated loops for the transmission and engine. For such a request, if the manufacturer can demonstrate single heat exchanging loop performance equivalent to separate, dedicated loops when combined for both technologies, the manufacturer may be granted the revised additive credit values of 3.0 g/mi CO_2 for a car or 6.4 grams/mi CO_2 for a truck, depending on the applicable vehicle category. Otherwise, if the level of performance for a single loop system falls short of the performance for separate cooling loops, the additive, active transmission and active engine warm-up credit values above will be decreased proportionately to reflect the lower performance of the single loop system. If the level of performance for a single loop system exceeds the performance for separate cooling loops, the manufacturer may receive the maximum, additive credit of 3.0 g/mi CO_2 for a car or 6.4 grams/mi CO_2 for a truck or, alternatively, can seek credits above these values using the demonstration methods for technologies not on the defined technology list.

5.2.8.4 Active Engine Warm-Up

Similar to active transmission warm-up, active engine warm-up uses waste heat from a vehicle's exhaust system to warm targeted parts of the engine, reducing friction and cold start enrichment requirements, and thereby increasing fuel economy. EPA assumed that similar to active transmission warm-up, a similar magnitude benefit would also be applicable for active engine warm-up. As a result, credit values for active engine warm-up are identical to those for active transmission warm-up, and are additive if a manufacturer can demonstrate the presence of both technologies (independent to one another, i.e., separate heating pathways) on a similar vehicle. Active engine warm-up test data provided by manufacturers resulted in the calculation of a similar emission reduction. Accordingly, the credit values of 1.5 grams/mi for cars and 3.2 grams/mi for trucks also apply for active engine warm-up.

As discussed above for Active Transmission Warm-Up, the Alliance and Volkswagen supported the credit value of 1.8 grams/mile for active engine warm-up but recommended that the definition be broadened to account for other methods of warm-up besides exhaust heat such as a secondary coolant loop. We agree with the commenters that the definition can appropriately be expanded and will discuss this further in the section below on technology definitions.

Also, as discussed above for Active Transmission Warm-Up, Chrysler advocated for separate car and truck credits and Honda for combined credit for single loop systems for active engine warm-up. Accordingly, our response above for active transmission warm-up applies to active engine warm-up as well. Therefore, we are finalizing separate car-truck credit values of 1.5 g/mi and 3.2 g/mi CO_2, respectively, for Active Engine Warm-Up and single loop systems must use the demonstration methods for technologies not on the defined list.

5.2.8.5 Definitions for Non-Thermal/Solar Advanced Load Reduction Technologies

Engine start-stop is a technology which enables a vehicle to automatically turn off the engine when the vehicle comes to a rest and restart the engine when the driver applies pressure to the accelerator or releases the brake. Off-cycle engine start-stop credits will only be allowed if the Administrator has made a determination under the testing and calculation provisions in 40 CFR part 600 that engine start-stop is the predominant operating mode. This technology may be coupled with an electric heater circulation system (or a technology that has a similar function), as described below, to receive maximum credit or may be implemented without an electric heater circulation systems for a lower amount of credit. For systems that accomplish the same level of performance as but do not utilize an electric heater circulation system, the maximum level of credit may be granted provided that equivalent level of performance is demonstrated by the requestor.

Electric heater circulation system is a system installed in a stop-start equipped vehicle, hybrid electric vehicle or plug-in hybrid electric vehicle that continues to circulate heated air to the cabin when the engine is stopped during a stop-start event. This system must be calibrated to keep the engine off for 1 minute or more when the external ambient temperature is 30 deg F and when cabin heat is demanded.

Active transmission warm-up means a system that uses waste heat from the vehicle to warm the transmission fluid to an operating temperature range quickly using a heat exchanger. This reduces the parasitic losses associated with the transmission fluid, such as losses related to friction and fluid viscosity, thereby increasing the overall transmission efficiency.

Active engine warm-up means a system using waste heat from the vehicle, to warm up targeted parts of the engine. This reduces engine friction losses and enables the closed-loop fuel control more quickly allowing for a faster transition from cold operation to warm operation, thereby decreasing CO_2 emissions, and increasing fuel economy.

5.2.9 Thermal (and Solar) Control Technologies

In the NPRM, EPA proposed a credit for technologies that reduce the amount of solar energy which enters a vehicle's cabin area, reduce the amount of heat energy build-up within the cabin when the vehicle is parked, and/or reduce the amount of cooling/heating energy required through measures which improve passenger comfort. The State of California Air Resources Board (CARB) has studied the effectiveness of many of these technologies, and had proposed including them in their Cool Cars and Environmental Performance Label programs.[43] The National Renewable Energy Laboratory (NREL) conducted an extensive research project as part of the SAE's Improved Mobile Air Conditioning Cooperative Research Program (I-MAC). The purpose of this program was to study the effectiveness of a variety of technologies which can reduce the amount of fuel used for the purpose of climate control in light-duty vehicles. In this study, known as the Vehicle Ancillary Loads Reduction Project, NREL estimated the effectiveness of window glazing/shades, paint, insulation, and seat and cabin ventilation technologies in reducing A/C-related fuel consumption and emissions.[44] EPA has evaluated these technologies and assigned a credit amount for each, based on their ability to reduce cabin air temperatures during soak periods and thereby reduce the amount of cooling/heating energy required to improve passenger comfort.

NREL's studies estimated that when these technologies are combined, a 12 °C reduction in cabin air temperature during soak will result in a 26% reduction in A/C-related fuel consumption, or a 2.2% reduction in fuel consumption (and by extension, CO_2 emissions) for each 1 °C reduction in cabin air temperature.[45] If the A/C-related CO_2 emissions impact is 13.8 g/mi for cars and 17.2 g/mi for trucks, this 2.2% reduction in CO_2 emissions results in a credit of 0.3 g/mi for cars (13.8 g/mi x 0.022) and a credit of 0.4 g/mi for trucks (17.2 g/mi x 0.022) for each degree centigrade reduction in cabin air temperature. There were no comments submitted on this overall approach for the thermal and solar control technologies.

5.2.10 Glazing

When a vehicle is parked in the sun, more than half of the thermal energy that enters the passenger compartment is solar energy transmitted through, and absorbed by, the vehicle's glazing (or glass).[44] The solar energy is both transmitted through the glazing and directly absorbed by interior components, which are then heated, and absorbed by the glazing, which then heats the air in the passenger compartment through convection and interior components through re-radiation. By reducing the amount of solar energy that is transmitted through the glazing, interior cabin temperatures can be reduced, which results in a reduction in the amount of energy needed to cool the cabin and maintain passenger comfort. Glazing technologies exist today which can reduce the amount of solar heat gain in cabin by reflecting or absorbing some of the infrared solar energy. NREL's study determined that cabin air temperature could be reduced by up to 9.7 °C with use of glazing technologies on all window locations. Technologies such as window films and coatings and absorptive or solar-reflective material within the glazing itself are currently used in automotive glazings, both for privacy (e.g., tinting) and improved passenger comfort. One measure of the solar load-reducing potential for glazing is Total Solar Transmittance, or Tts, which expresses the percentage of solar energy which passes through the glazing. Lower Tts values for glazing result in lower cabin temperatures during solar soak periods. EPA considers the April 15, 2008 version of the International Organization for Standardization's (ISO) 13837 standard to be the appropriate method for measuring the solar transmittance of glazing used in automotive applications.

A method for estimating the effect of the solar performance of glazing technologies was developed by EPA and CARB, with input from NREL and the Enhanced Performance Glass Automotive Association (EPGAA). This method utilizes the measured Tts of the glazing used in a vehicle to estimate its effect on cabin temperature during soak conditions. The contribution that each glass/glazing location on the vehicle has on the overall interior temperature reduction is determined by its Tts (relative to a baseline level) and its area. For purposes of this proposal, EPA considers the baseline Tts to be 62% for all glazing locations, except for rooflites and rear side glazings of CUVs, SUVs, and minivans, which have a baseline Tts of 40%.[bb] The relationship between the Tts value for glass/glazing and a corresponding reduction in interior temperature is has been established using the data from NREL testing, as shown in Table 5-35.

Table 5-35 Effect of Tts on Interior Temperature Reduction

Glass/Glazing Position	Baseline Tts for Glazing Type (%)	Solar Control Tts	Measured Breath Air Temperature Reduction (°C)	Estimated Temperature Reduction from 23.8 °C Baseline (°C)
All	62 (solar absorbing)	40	9	15
All	62 (solar absorbing)	40	10	16
All	75 (light green)	50	8	8
All	75 (light green)	60	6	6

[bb] Glazing materials that are not subject to the requirement of >70% luminous transmittance, per 49 CFR 571.205, are often darkened "privacy" glass, and for this credit are subject to the lower baseline Tts of 40%.

Using the NREL data and estimated temperature reductions, the linear correlation between Tts and breath air (interior) temperature reduction was developed, and is shown in Figure 5-11.

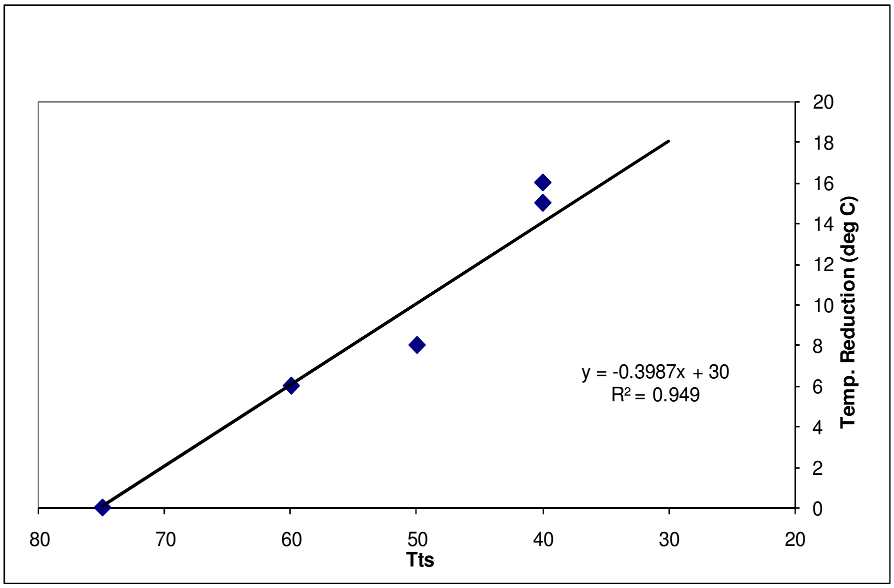


Figure 5-20 Correlation between Tts and Estimated Interior Temperature Reduction

From the slope of this correlation between the Tts value and reduction in cabin air (also referred to as "breath air") temperature, a method for estimating the amount of interior temperature reduction (in degrees Celsius) for a specific glazing location and its Tts specification was developed, and is shown in Equation 5-6 .

Equation 5-6 – Estimated Breath Air Temperature Reduction for Glazing with Improved Solar Control

$$Estimated\ Temperature\ Reduction = 0.3987\ x\ (Tts_{baseline} - Tts_{new})$$

where $Tts_{baseline}$ = 62 for windshield, side-front, side-rear, rear-quarter, and backlite locations, and 40 for the rooflite location and rear side windows for SUVs, CUVs and Minivans which are typically darkened privacy glass.

To determine the total amount of glass/glazing credit generated for a given vehicle, the contribution (in terms of estimated temperature reduction) for each glazing location is calculated using the glass manufacturer's Tts specification. The contribution of each glazing location is then normalized to determine the effect each glazing location on the overall vehicle temperature reduction. The method for normalizing the contributions is to multiply the estimated temperature reduction of Equation 5-6 by the ratio of the glazing area of each location divided by the total glazing area of the vehicle. The total vehicle temperature reduction is the sum of the normalized contributions for each location. To calculate the glazing credit generated (in grams of CO2 per mile), the sum of the total vehicle temperature reduction (in degrees Celsius) multiplied by 0.3 for cars, or 0.4 for trucks.

We received several comments on the glazing credit. The ICCT agreed with the proposed credit and the basis for the credit described in the draft TSD. In contrast, there were multiple comments that fell into three main categories: 1) accounting for the overall glazing surface area in the calculations and a minimum level of solar transmittance, 2) concerns regarding metallic glazing and incentivizing this technology, and 3) granting of credit for polycarbonate (PC) glazing technology.

The Alliance, Enhanced Protective Glass Automotive Association (EPGAA), Guardian and Pittsburgh Glass Works (PGW) commented on the calculation accounting for the glazing surface area where solar control glazing is applied. Each commenter recommended that a factor accounting for the total surface area of the glazing be included in the calculation or to account for increased effectiveness of solar control glazing for vehicles with larger total glazing area. In addition, the Alliance suggested that a limit of 62% Tts be used for a technology to be eligible for the glass/glazing credit. In proposed 40 CFR §86.1866-12(d)(1)(i)(C), we included an equation to calculate the glazing credit as follows:

$$\text{Credit} = \left[Z \times \sum_{i=1}^{n} \frac{T_i \times G_i}{G} \right]$$

where the "G" term in this equation represents "the total glass area of the vehicle, in square meters and rounded to the nearest tenth." Therefore, the current equation takes into account the total glazing surface area. As far as applying a limit of 62% for the glazing credit, we agree with the commenter and the "T" term in the equation above represents the "the estimated temperature reduction for the glass area of each window i." The T-term is determined using the following equation:

$$T_i = 0.3987 \times (Tts_{base} - Tts_{new})$$

where the "Tts_{base}" term is defined as "62 for the windshield, side-front, side-rear, rear-quarter, and backlite locations, and 40 for rooflite locations and rear side windows for SUVs, CUVs and Minivans which are typically darkened privacy glass." Therefore, the equation for solar transmittance currently takes this into account and uses the 62% level as the baseline. As a result, any glazing with a solar transmittance level of more than 62% (i.e., a higher value implies that more solar energy is transmitted to the passenger compartment/cabin) would result in a negative credit value. Accordingly, we are finalizing the equations above as proposed since they address the commenter's concerns.

There were multiple comments with concerns regarding the use of metallic glazing from the Crime Victims Unit of California (CVUC), California Manufacturers & Technology Association (CMTA), California State Sheriffs' Association (CSSA), California Police Chiefs Association (CPCA), California Narcotic Officers' Association (CNOA), CTIA - The Wireless Association, Garmin, Honda and TechAmerica. Many commenters stated that low Tts glazing uses metallic films or small metallic particles and that the credit for glazing may unintentionally incentivize the use of this type of glazing, metallic glazing, which can potentially interfere with signals for global positioning systems (GPS), cell phones, cell-phone based prisoner tracking systems, emergency and/or electronic 911 (E911) calls, and other signals emanating from within or being transmitted to the vehicle's passenger compartment/cabin. In addition, some commenters cited this concern as the reason that the California Air Resources Board (CARB) removed their mandate for metallic glazing from the "Cool Cars" Regulation in California.

To address these concerns, we met with the Enhanced Protective Glass Automotive Association, which represents the automotive glass manufacturers and suppliers, and representatives from the automotive glass industry including PGW, Guardian, and AGC to discuss the concerns with metallic glazing and the potential for signal interference and/or radio frequency (RF) attenuation (details of this meeting are available in EPA docket # EPA-HQ-OAR-2010-0799 and NHTSA docket #NHTSA-2010-0131). At this meeting, evidence was provided to the agencies showing that, in general, any glazing material can create signal interference and RF attenuation, and depending on the situation, RF attenuation and signal interference can occur without the presence of metallic glazing material. There was no statistically-significant increase in signal interference and RF attenuation when metallic glazing was used, and there are deletion areas or zones without metallic solar control around the edges and specific cut-outs in the metallic solar control films near the center of the dash area to minimize signal interference and RF attenuation. Following the meeting, a list of vehicles that currently use metallic glazing was also provided to the agencies demonstrating that this technology is currently in-use without significant signal interference/RF attenuation issues being raised.

In addition, we received comments from the California Air Resources Board (CARB) in response to the comments on the Cool Cars Regulation. The CARB stated that the reason they did not finalize a mandate for metallic glazing in the Cool Cars Regulation was primarily the timing for when the signal interference and RF attenuation concerns were raised. They also clarified that they were not requiring a specific type of glazing and that the performance-based approach ultimately adopted in the Advanced Clean Cars Regulation accomplished the same objectives as proposed under the Cool Cars Regulation. Finally, CARB performed testing of signal interference and RF attenuation by CARB (see test results in EPA docket # EPA-HQ-OAR-2010-0799-41752) echoing the findings of the automotive glass industry that there is "[n]o effect of reflective glazing observed on monitoring ankle bracelets or cell phones" and that any "[e]ffects on GPS navigation devices [are] completely mitigated by use of [the] deletion window" placing either the device or the external antennae in this area. CARB urged EPA to finalize the proposed credit values for glass and glazing as proposed.

Based on this information, the agencies are finalizing the proposed credit values and calculation procedures for glazing. First, we are not mandating a particular technology for glazing. The final version of the off-cycle technology menu is technology neutral with manufacturers able to select the glazing technology based on desired performance. There are other technologies capable of rejecting solar load from the cabin and suppliers, in their comments, were keen to point out these alternatives. Second, we did not see evidence contrary to the information that the automotive glass industry and CARB presented showing that there would be significant adverse effects on signal interference and RF attenuation. However, to allay the commenters' concerns, we will emphasize that manufacturers strongly consider and evaluate the potential for signal interference and RF attenuation in their vehicle design and glazing technology when requesting the solar control glazing credit.

Next, the American Chemistry Council (ACC), Bayer Material Science, California Manufacturers and Technology Association, CTIA-The Wireless Association, Garmin, SABIC Innovative Plastics, and the Society of Plastics Industry all commented that benefits of polycarbonate (PC) glazing should also be reflected in the amount of the menu credit for glazing, and therefore that the automatic credit amount not be restricted to metallic glazing. These commenters pointed to PC glazing's reduced thermal conductivity compared to glass, which can reduce the amount of heat transmitted into the vehicle's passenger compartment/cabin, as well as to the reduced weight of PC glazing compared to other materials, potentially having mass reduction benefits as well. Some commenters advocated for a separate credit for PC glazing equivalent to the overall glazing credit we proposed. Further, SABIC Innovative Plastics supplied an equation to calculate thermal conductivity similar to the one we proposed for calculating Tts.

As stated above, we are not mandating a particular technology for glazing and, therefore, do not need believe that it is necessary to offer a separate PC glazing credit since this credit covers all types of glazing technologies. Also, one of the main issues with allowing a separate credit for PC glazing is that it is more effective when the vehicle is in motion since air flow cools the glazing surface and less thermal conduction occurs. Thus, this application is limited to a narrower operating regime and would have less effectiveness in that regime considering that the cabin will be cooler and require external air flow and internal air conditioning.

Additionally, we do not have information, at this time, to support the equation that SABIC supplied to account for thermal conductivity. In contrast, for solar transmittance, there are established ISO procedures (ISO 13837) that can be used and referenced to ensure a consistent basis for information supporting the credit request. We need to have a similar, established set of procedures to validate the equations, and substantiate a credit. Therefore, we are not including the specific equations used to calculate thermal conductivity for the defined technology list at this time. If manufacturers still believe that there may be some additional benefit, they may apply for additional glazing credit using the demonstration methods for technologies not on the defined technology list.

Finally, there was a comment from Honda advocating for the use of direct solar transmittance (Tds) as a measure of solar/thermal control benefits rather than Tts. While there may be some benefit to the use of Tds, we are not aware of sufficient data to determine 1) the total effectiveness of Tds and 2) if the amount of glazing credit is appropriate based on the effectiveness of Tds. Therefore, we are not including Tds technology as part of the glazing credit on the defined technology list. However, this technology may be eligible to generate off cycle credits based on the case-by-case demonstration procedure in the rules.

In summary, the credits, definitions and terminology for glazing will be finalized in today's action as proposed.

5.2.11 Active Seat Ventilation

The NREL study investigated the effect that ventilating the seating surface has on the cooling demand for a vehicle. By utilizing a fan to actively remove heated, humid air that is typically trapped between the passenger and the seating surface, passenger comfort can be improved, and NREL's Thermal Comfort Model predicted that A/C system cooling load could be reduced, and a 7.5% reduction in A/C-related emissions can be realized.[45] While seat ventilation technology does not lower the cabin air temperature, it indirectly affects the load placed on the A/C system through the occupants selecting a reduced cooling demand due to their perception of improved comfort. Using the EPA estimate for the A/C-related CO2 emissions impact of 13.8 g/mi for cars and 17.2 g/mi for trucks, a 7.5% reduction in CO2 emissions with active seat ventilation results in a credit of 1.0 g/mi for cars (13.8 g/mi x 0.075) and a credit of 1.3 g/mi for trucks (17.2 g/mi x 0.075).

We received four comments on Active Seat Ventilation. The Alliance supported our proposed credit values of 1.0 g/mi for cars and 1.3 g/mi for trucks. In contrast, ICCT felt these numbers were modest based on the limited NREL dataset we used and other studies from the University of Denmark and a journal on "Ergonomics" that showed up to a 6.4 deg Celsius change in cabin temperature could be tolerated with cooled seats, equating to a credit of 1.9 g/mi for cars and 2.6 g/mi for trucks. However, as ICCT also points out, this is highly dependent on driver comfort perception and response and the real-world impact may be lower than anticipated in the studies the commenter cited. Therefore, we are finalizing the menu default credit values of 1.0 g/mi for cars and 1.3 g/mi for trucks in today's action as proposed. In addition, the Alliance and MEMA commented that the definition for Active Seat Ventilation was too narrowly defined since it only contemplated a suction-type system to pull heat and reduce moisture from the seating surface. Specifically, they stated that the use of a forced-air system to push heat and reduce moisture from the seating surface is just as effective. We agree with these comments and are finalizing a broadened definition that allows for forced-air as well as suction-type systems. Finally, the Alliance also suggested that active seat ventilation technology need only be applied to the front seats in order to qualify for the credit. We agree with this comment since some vehicles do not have seat heaters on the rear seats or in the case of vehicles that only have two seats. Therefore, we will specify that, at a minimum, the front driver and passenger seat, or in the case of a two-seat vehicle, driver and passenger seats, must have active seat ventilation for a vehicle to be eligible for credit. In summary, we are finalizing the credit values of 1.0 g/mi for cars and 1.3 g/mi for trucks, as proposed, with the modifications to the definition for active seat ventilation technology.

5.2.12 Solar Reflective Paint

As the vehicle's body surface is heated by solar energy when parked, heat is transferred to the cabin through conduction and convection. Paint or coatings which increase the amount of infrared solar energy that is reflected from the vehicle surface can reduce cabin temperature during these solar soak periods. While the amount of heat entering the cabin through the body surface is less than that which enters through the glazing, its effect on cabin air heat gain is measureable. NREL testing estimated that solar-reflective paint and coatings can reduce cabin air temperature by approximately 1°C, whereas glazing technologies can reduce cabin air temperature by up 10°C. Using the EPA estimate for credits due to cabin air temperature reductions of 0.3 g/mi for cars 0.4 g/mi for trucks for each degree centigrade of temperature reduction, a 1.2°C reduction due to solar reflective paint results in a credit of 0.4 g/mi for cars and 0.5 g/mi for trucks.

The comments on solar reflective paint were primarily supportive of the credit amount we proposed of 0.4 g/mi for cars and 0.5 g/mi for trucks for a 1.2°C of temperature reduction. The Alliance supported this level of credit, although they thought it might be ambitious due to the worst case test conditions in the National Renewable Energy Laboratory (NREL) we used as the basis for calculating the credit. The ICCT supported the credit since it met their "general principle of being verifiable and additive."

Honda commented that the solar reflective paint credit should only apply to certain colors on a sales-weighted basis since some colors cannot reflect at least 65 percent of the impinging infrared solar energy as required under ASTM standards E903, E1918–06, or C1549–09 for measuring solar reflectiveness. In addition, Honda also stated that the credit should only be applicable to the horizontal surfaces of the vehicle since these areas will be exposed to the most solar loading where solar reflective paint would be more effective. The credit for solar reflective paint is performance based (i.e. it is a scalar) so a manufacturer would have to demonstrate what level of temperature reduction they are achieving. Therefore, a lower level of credit would be granted under Honda's approach if a certain color of paint demonstrates a lower level of temperature reduction. Regarding the comment on application of the credit for only horizontal surfaces, it may be possible that other surfaces (e.g., side quarter/door panels) under direct solar loading may be beneficial but this benefit is limited by the orientation of the vehicle to sunlight. As a result, we can't guarantee that other areas of the vehicle will be exposed, if at all, to the extent of the horizontal surfaces. Therefore, we agree that the horizontal surfaces are the prime areas of benefit and will revise the definition for solar reflective paint to state that only the horizontal surfaces utilizing solar reflective paint will receive any credit under the technology menu. For the same reason, we do not believe that there ever could be a demonstration that other-than horizontal surfaces would generate off-cycle credits and therefore other-than-horizontal surfaces would not be eligible to generate off-cycle credits under a case-by-case demonstration. In summary, we will finalize the credit of 0.4 g/mi for cars and 0.5 g/mi for trucks for a 1.2 degrees centigrade of temperature reduction in today's action with the revised criteria that only the horizontal surfaces utilizing solar reflective paint will receive any credit.

5.2.13 Passive and Active Cabin Ventilation

Given that today's vehicles are fairly well sealed (from an air leakage standpoint), the solar energy that enters the cabin area through conductive and convective heat transfer is effectively trapped within the cabin. During soak periods, this heat gain builds, increasing the temperature of the cabin air as well as that of all components inside the cabin (i.e. the thermal mass). By venting this heated cabin air to the outside of the vehicle and allowing fresh air to enter, the heat gain inside the vehicle during soak periods can be reduced. The NREL study demonstrated that active cabin ventilation technology, where electric fans are used to pull heated air from the cabin, a temperature reduction of 6.9 °C can be realized. For passive ventilation technologies, such as opening of windows and/or sunroofs are and use of floor vents to supply fresh air to the cabin (which enhances convective airflow), a cabin air temperature reduction of 5.7 °C can be realized.[45] Using the EPA estimate for credits due to cabin air temperature reductions of 0.3 g/mi for cars 0.4 g/mi for trucks for each degree centigrade of temperature reduction, a 6.9 °C reduction due to active cabin ventilation results in a credit of 2.1 g/mi for cars and 2.8 g/mi for trucks. For passive cabin ventilation, a 5.7 °C temperature reduction results in a credit of 1.7 g/mi for cars and 2.3 g/mi for trucks.

There were two main commenters regarding passive and active cabin ventilation: the Alliance and ICCT. The Alliance felt that a significant credit was necessary to enable implementation and, thus, supported the proposed credit values. Their only suggestion was to broaden the definition for passive cabin ventilation from "…ducts or devices which utilize convective airflow to move heated air from the cabin interior to the exterior of the vehicle." to include the word "methods" (e.g., "…ducts, devices or methods…") since there are other ways to perform passive cabin ventilation without the use of ducts or devices. For example, the Toyota Prius and other vehicles will lower the side windows 1/2 to 1 inch to allow for convection. This works absent a duct or device and the broadened definition would provide for such methods.

The ICCT commented that the NREL report used as the basis for this credit lacked sufficient data and identified the possibility of intrusion in the case of floor-level ventilation. Therefore, ICCT stated that the credit for active/passive cabin ventilation should be deferred to establish a real-world benefit and a proper verification benchmark can be established. In response, the Alliance submitted supplemental comments presenting data from vehicles in the existing fleet and a study commissioned by General Motors and conducted by NREL to examine various active and passive cabin ventilation technologies. As stated by the Alliance, this study demonstrated the ability to achieve cabin temperature reductions on five of the twelve vehicles of greater than the 6.9 degrees Celsius in the NREL report cited in the TSD, with temperatures reductions as high as 11.4 and as low as 7.2 degrees Celsius. The agencies have carefully evaluated these studies and believe that they address the ICCT's concerns regarding supporting data to support the level of credit proposed.

Therefore, we are finalizing the default credit for active/passive cabin ventilation as proposed. In addition, as discussed above, we agree with the comments regarding the definition for active/passive cabin ventilation and will expand the definition to include "methods" that may be employed to achieve the same objective as "ducts and devices."

5.2.14 Summary of Thermal (and Solar) Control Credits

The amount of credit that a manufacturer can generate for thermal and solar control technologies is shown in Table 5-36.

Table 5-36 Off-Cycle Credits for Thermal Control Technologies

Thermal Control Technology	Estimated Breath Air Temp. Reduction	Credit (g CO2/mi)	
		Car	Truck
Glass or glazing	up to 9.7 °C	up to 2.9	up to 3.9
Active Seat Ventilation	N/A*	1.0	1.3
Solar reflective paint	1.2 °C	0.4	0.5
Passive cabin ventilation	5.7 °C	1.7	2.3
Active cabin ventilation**	6.9 °C	2.1	2.8

* Active seat ventilation is not a temperature reduction technology, but rather a comfort control technology, capable of reducing A/C-related emissions by 7.5%

** Active cabin ventilation has potential synergies with solar panels as described in Chapter 5.2 of this joint TSD.

To generate off-cycle thermal control credits – up to a maximum of 3.0 g/mi for cars, and 4.3 g/mi for trucks - a vehicle must be equipped with the thermal control technology, in accordance with the specifications and definitions in this proposed rulemaking. If a technology meets the specifications, its use in a vehicle will generate credits, in accordance with the value set forth in the thermal control technology list. The one exception to a single credit value for a technology is glazing technologies, where the method for determining the credit is described in section 5.2.10.

5.2.15 Definitions for Solar Control Credit Technologies

Credit for solar control technologies can be generated for MY 2017-2025 vehicles which utilize them. In the absence of a performance test to measure the affect of these technologies, For all solar control technologies except glazing, EPA will rely on manufacturers complying with a specification for, or description of, each technology to assure that the emissions reducing benefits are be realized in real-world applications. Below are the descriptions and specifications that EPA is adopting for the solar control technologies listed in Table 5-36. EPA will use these definitions and specifications to determine whether the credits are applicable to a vehicle.

- *Active Seat Ventilation* – device which draws air, forces air or transfers heat from the seating surface which is in contact with the occupant and exhausts it to a location away from the seat. At a minimum, the front driver and passenger seat must utilize this technology for a vehicle to be eligible for credit. If the vehicle only has two seats, then these seats must have active seat ventilation for a vehicle to be eligible for credit.
- *Solar Reflective Paint* – vehicle paint or surface coating applied to the horizontal surfaces, including the rear decklid and cabin roof, which reflects at least 65 percent of the impinging infrared solar energy, as determined using ASTM standards E903, E1918-06, or C1549-09
- *Passive Cabin Ventilation* – ducts, devices or methods which utilize convective airflow to move heated air from the cabin interior to the exterior of the vehicle
- *Active Cabin Ventilation* - devices which mechanically move heated air from the cabin interior to the exterior of the vehicle

5.2.16 Summary of Credits

Table 5-37 summarizes the preapproved technologies and off-cycle credits available to manufacturers. If manufacturers wish to receive off-cycle credits for other technologies, they must follow the procedures laid out in section III.C.5 of the Preamble and in the regulations at 40 CFR §86.1869-12 (b) and (c).

Table 5-37: Initial off-cycle credit estimates (Maximum Available Credits)

Technology		Adjustments for Cars		Adjustments for Trucks	
		g/mi	gallons/mi	g/mi	gallons/mi
+High Efficiency Exterior Lights* (at 100 watt savings)		1.0	0.000113	1.0	0.000113
+Waste Heat Recovery (at 100W)		0.7	0.000079	0.7	0.000079
+Solar Panels (based on a 75 watt solar panel)**	Battery Charging Only	3.3	0.000372	3.3	0.000372
	Active Cabin Ventilation and Battery Charging	2.5	0.000282	2.5	0.000282
+Active Aerodynamic Improvements (for a 3% aerodynamic drag or Cd reduction)		0.6	0.000068	1.0	0.000113
Engine Idle Start-Stop	w/ heater circulation system#	2.5	0.000282	4.4	0.000496
	w/o heater circulation system	1.5	0.000169	2.9	0.000327
Active Transmission Warm-Up		1.5	0.000169	3.2	0.000361
Active Engine Warm-up		1.5	0.000169	3.2	0.000361
Solar/Thermal Control		Up to 3.0	0.000338	Up to 4.3	0.000484

* High efficiency exterior lighting credit is scalable based on lighting components selected from high efficiency exterior lighting list (see Joint TSD Section 5.2.3, Table 5-21).
** Solar Panel credit is scalable based on solar panel rated power, (see Joint TSD Section 5.2.4). This credit can be combined with active cabin ventilation credits.
# In order to receive the maximum engine idle start stop, the heater circulation system must be calibrated to keep the engine off for 1 minute or more when the external ambient temperature is 30 deg F and when cabin heat is demanded (see Joint TSD Section 5.2.8.1).
+This credit is scalable; however, only a minimum credit of 0.05 g/mi CO2 can be granted.

5.3 Full-Size Pickup Truck Credits

The agencies recognize that the MY 2017-2025 standards will be challenging for large trucks, including full size pickup trucks that are often used for commercial purposes, and so are taking steps to incentivize the penetration into the marketplace of “game changing” technologies for these pickups, including their hybridization. EPA proposed and is adopting per-vehicle credits for manufacturers that sell substantial numbers of mild or strong hybrid full size pickup trucks. The credit is 10 g/mi and 20 g/mi for mild and strong hybrids, respectively. EPA also proposed and is adopting a performance-based incentive credit for full size pickup trucks that achieve significant emissions reductions below the target level that corresponds to their footprint. The credit is 10 g/mi for pickups achieving 15% better CO_2 than their target, and 20 g/mi for pickups achieving 20% better CO_2 than their target. Access to all of these credits in any given model year is conditioned on achieving a minimum penetration of the technology in a manufacturer’s full size pickup truck sales fleet:

- For strong hybrid credits: 10% in each model year 2017 through 2025.
- For mild hybrid credits: 20-30-55-70-80% in model years 2017-2018-2019-2020-2021, respectively.

- For "20 percent better" performance-based credits: 10% in each model year 2017 through 2025.
- For "15 percent better" performance-based credits: 15-20-28-35-40% in model years 2017-2018-2019-2020-2021, respectively.

A number of comments were received on the proposed minimum penetration thresholds. These comments, and EPA's response to them, are discussed in preamble section III.C.3. Credits are not available after 2025 for strong hybrids and "20 percent better" performance, or 2021 for mild hybrids and "15 percent better" performance. Unlike the hybrid credits, the performance-based credits have no technology or design requirements. Automakers can use any technology as long as the vehicle's CO_2 performance is at least 15% or 20% below its footprint-based target. A vehicle cannot receive both the hybrid and performance-based credit. EPA and NHTSA are coordinating to allow manufacturers to include "fuel consumption improvement values", equivalent to these EPA CO_2 credits, in the CAFE program.

5.3.1 Full-Size Pick-up Truck Definition

As proposed, EPA is defining a full size pickup truck based on minimum bed size and hauling capability, as detailed in 86.1866-12(e) of the regulations being adopted. This definition is meant to ensure that the larger pickup trucks which provide significant utility with respect to payload and towing capacity, as well as open beds with large cargo capacity, are captured by the definition, while smaller pickup trucks which have more limited hauling, payload and/or towing are not covered. A full size pickup truck is defined as meeting requirements (1) and (2) below, as well as either requirement (3) or (4) below:

1) Bed Width -- The vehicle must have an open cargo box with a minimum width between the wheelhouses of 48 inches, measured as the minimum lateral distance between the limiting interferences (pass-through) of the wheelhouses, excluding any transitional arc, local protrusions, and depressions or pockets (dimension W202 in SAE Procedure J1100). An open cargo box means a cargo bed without a permanent roof or cover. Vehicles sold with detachable covers are considered "open" for the purposes of these criteria. And--

2) Bed Length -- The length of the open cargo box must be at least 60 inches, as measured at both the top of the body and at the bed floor (dimensions L506 and L505 in SAE Procedure J1100). And--

3) Towing Capability – the gross combined weight rating (GCWR) minus the gross vehicle weight rating (GVWR) must be at least 5,000 pounds. Or--

4) Payload Capability – the GVWR minus the curb weight (as defined in 40 CFR 86.1803) must be at least 1,700 pounds.

This definition is being finalized as proposed. The comments that were received on the definition, and our responses, are discussed in preamble section II.F.3.

5.3.2 Hybrid Pickup Truck Technology

5.3.2.1 Mild Hybrid Technology

Often a mild hybrid is characterized by the addition of a belt-driven starter-alternator of higher power capacity than a standard alternator. The drive belt system also typically has a feature that enables the belt tension to be maintained at proper levels during generator operation as well as when the starter-alternator is used to start the engine. Alternatively, an axial motor can be mounted on the crankshaft, usually in the bell housing before the transmission. This motor can be directly attached to the engine, or can be clutched to decouple it from the engine. The vehicle uses a conventional transmission such as an automatic, manual, CVT, or DCT with an appropriate conventional coupling such as a torque converter or clutch.

The battery can be between 36V to over 150V nominal; generally the higher the voltage, the higher the performance of the system. Most mild hybrid pickups are expected to offer at least 100V of battery voltage due to the higher power requirement of these heavy vehicles. Mild hybrids are capable of start-stop operation and regenerative braking, but unlike strong hybrids they are not capable of any significant electric-only operation.

Mild hybrids are less capable than strong hybrids because of lower power capability, but mild hybrids are lower cost and may be easier to adapt to some vehicles without making major powertrain, chassis or body changes.

5.3.2.2 Strong Hybrid Technology

Strong hybrids can take several forms. One type has an integrated transmission-drive motor system with a large, powerful electric drive motor-generator (often two motors). The transmission usually is specifically designed to integrate the motor-generator(s) and often the coupling between the engine and transmission such as a torque converter is removed with its functions handled by the electric drive motor system. The transmission can also be replaced by a power split device that uses a planetary gearset and two motor-generators, or a P2 arrangement can be used with a conventional transmission augmented by an electric motor. Strong hybrids typically have high voltage battery packs over 300 V to provide the high power necessary for their increased capability.

Strong hybrids are capable of start-stop operation, have significant braking regeneration capability, and are often capable of driving exclusively on battery power up to 35-45 mph. They are also capable of launching the vehicle on electric drive alone, although they typically cannot accelerate above 15-20 mph while operating on electric drive exclusively.

5.3.3 Mild and Strong Hybrid Pickup Truck Definitions

In addition to meeting the definition for a full-size truck, a vehicle must meet additional design and performance requirements to be eligible for the hybrid full-size truck incentive. Mild and strong hybrids must have both stop-start capability and regenerative braking. Additionally, the level of hybridization (mild or strong) is characterized by the amount of energy recovered into the battery: at least 65% for strong hybrids, and at least 15% but less than 65% for mild hybrids. These thresholds and the methodology for determining the amount of recovered energy are discussed below.

5.3.3.1 Measurement of Recovered Energy

EPA is incorporating a metric – the total percentage of available vehicle energy recovered over the test cycle – as a way to define levels of hybrid vehicles. For a given vehicle and road load profile (characterized by ETW and A, B and C dyno test "coastdown" coefficients), a theoretical amount of required braking energy can be calculated over the city and highway test cycles. This maximum braking energy is the sum of the extra braking force needed to slow the vehicle enough to follow the test cycle trace upon decelerations. Hybrids recapture a portion of this energy by driving the electric motor (in reverse) as a generator, which ultimately provides electrical power to the battery pack. Depending on the level of hybridization, this amount of recaptured energy can range between a few percent of total available braking energy, up to and potentially exceeding 100% of all braking energy (since some manufacturers also charge the battery via excess engine load when it is beneficial to do so).

This metric is a way to simplify the characterization of a hybrid as a "mild" or "strong" hybrid. Batteries and motors must increase in scale to recover energy at a greater rate. As the power rating of the motor and battery increases, a greater percentage of energy can be recovered on rapid decelerations. So, all key facets of a hybrid system – the battery pack size and power rating, the motor rating, etc. – are implicitly reflected in the percentage of energy recovered.

The procedure involves calculating the available braking energy on the FTP city cycle using the equation derived below. This value is compared to the actual energy recovered by the vehicle during FTP city cycle testing. Since energy into and out of the hybrid drive system battery is a standard part of emissions testing of hybrid vehicles, this procedure introduces no additional test burden. However, energy flow into the battery must be separated from the sum of energy into and out of the battery which is typically less than 1% of total fuel energy used during the test.

The fact that some of the energy going into the battery may come directly from the engine means that the measured energy flow over the FTP is not, strictly speaking, just the recovered braking energy. Some manufacturers commenting on the proposal expressed concern that this would make the categorization of mild and strong hybrids subject to gaming by manufacturers seeking credits. They suggested that we replace this metric with one that only integrates current flow during decelerations (with correspondingly revised thresholds for percentage of energy recovered), and that we also add a second metric based on battery-supplied tractive effort only.

We have evaluated these concerns and have concluded that the proposed metric remains adequate for our purposes, and furthermore has the advantage of being simpler and easier to measure than other metrics, such as measured current flow only during deceleration periods with zero fuel flow, or only during applied braking. Even these metrics would not completely remove the potential for inclusion of engine-to-battery energy flow as sought by the commenters. The data that EPA collected on a 2-mode hybrid truck, discussed below, indicates that there is a strong correlation between EPA's proposed metric and the energy recovery metric suggested by commenters. Moreover, EPA believes that adding more constraints in the characterization of hybrids, such as battery-only traction, would put too much emphasis on the particular hybrid design strategy, and our preference is to remain neutral on how these technologies are implemented. More fundamentally, we feel the total cycle energy-to-battery metric, matched with the corresponding mild and strong HEV thresholds we are setting, provides a fair indication of the degree of hybridization in the design because, given the expense involved in using larger electrical components, we would expect any energy flow directly from the engine to the battery to stem from real efforts to optimize HEV design for performance and fuel economy rather than from gaming for credit generation. This view is backed by the fact that the practice is common in today's hybrids where there is no potential for credits. To keep from causing confusion, we are avoiding calling the parameter that is derived from current measurement "recovered braking energy," instead simply calling it "recovered energy."

The measured energy into the battery is divided by the total calculated braking energy to determine if the vehicle is a mild or strong hybrid. We proposed that the recovered energy for a mild hybrid must be greater than or equal to 15% and less than 75% of the calculated available braking energy, and that the recovered energy for a strong hybrid must be at or above 75%. We based these proposed thresholds on available test data collected on hybrid vehicles, none of which were large pickup trucks. Chrysler commented that the 75% threshold for strong hybrids, though it may be appropriate for passenger cars, is too demanding for large pickup trucks designed with powerful braking systems to safely handle large towing loads. In response, EPA has conducted tests, using the methodology described in this TSD section, on a Silverado 1500 2-mode HEV truck. This is the only large light-duty truck currently on the market that is generally considered to be a strong hybrid.[46] [47] The results over 6 repeat tests varied from 68% to 78%. Based on this testing, we believe 65% is a more appropriate threshold than the proposed 75% for defining strong hybrids, and so are adopting this threshold into the final regulations. We are retaining the proposed 15% threshold for mild hybrids, consistent with comments received.

It should be kept in mind that these thresholds and the associated metric for evaluating candidate hybrids are intended to provide a general, non-technology-specific parallel to the hybrid technology overview in section 5.3.2 above. Their purpose is to clearly, fairly, and as simply as possible define eligibility for credits. They are not meant to be used in any way as an industry standard for these terms. We recognize too that technology evolution or new information may make it helpful to reconsider these criteria, and believe that the mid-term review may provide a suitable forum for doing so.

5.3.3.2 Spreadsheet documentation and calculation methodology details

Equation 5-7 defines the brake energy recovery efficiency (expressed as a percentage), or $\eta_{recovery}$:

Equation 5-7:

$$\eta_{recovery} = \frac{E_{recovered}}{E_{brake\_max}}$$

$E_{recovered}$, the total energy recovered over the 4-bag FTP test (in kWh) is calculated in Equation 5-8.

Equation 5-8:

$$E_{recovered} = \frac{V\int i(t)dt}{3600*1000}$$

With i(t) defined as measured current into the battery (in amps) and V defined as the nominal battery pack voltage. Current flowing out of the battery (discharge) is not included. Battery current is measured via a current clamp probe, mounted directly upstream of the battery pack. Both battery current and vehicle speed data should be collected at a sampling rate of 10 Hz.

We received comments expressing concern that nominal voltage is a poorly-defined term, determined in the industry in a variety of ways, and is therefore subject to gaming. In response, and after discussion with industry representatives including developers of SAE J2711,[48] we are defining nominal voltage in the following manner: Determine nominal voltage of the battery by taking one battery voltage measurement immediately following "key-on" for the FTP, taking a second battery voltage measurement immediately prior to "key-off" for the FTP, and then averaging the pre- and post-FTP voltages. The initial voltage measurement may occur any time between "key-on" and up to 10 seconds following the "key-on" event. The second voltage measurement may occur up to 10 seconds before the "key-off event". Based on data we have reviewed from actual vehicle testing, we expect that this straightforward methodology will be adequate for the purposes of this credit program, because current flow at these times is typically very low.[49] However, if a manufacturer's test data shows that the absolute value of the measured current to and from the battery during either of the voltage measurements exceeds 3.0% of the maximum absolute value of the current measured over the FTP, the manufacturer is expected to develop an alternative means of determining nominal voltage, subject to EPA approval.

In order to allow verifiable measurements of nominal voltage, the manufacturer wishing to make use of this optional credit provision will need to broadcast battery pack voltage on an on-board diagnostics (OBD) parameter ID (PID) channel. Battery voltage is already publically available on enhanced PIDs but the protocol is not consistent across manufacturers. Making the data available on an OBD PID will make the procedure for recording battery voltage consistent across vehicle manufacturers and will allow verification of nominal voltage measurements during confirmatory and other testing by EPA.

E_{brake_max} (kWh) is calculated by integrating required braking power (P_{brake}) at each point in the test cycle[cc] over the entire test, shown in Equation 5-9. For clarity, the prescribed vehicle speed test schedule (not the recorded vehicle speed test data) is used in this calculation.

Equation 5-9

$$E_{brake\_\max} = \frac{\int P_{brake}(t)dt}{3600}$$

P_{brake} (kW) – the vehicle braking power required to follow the drive trace during decelerations – represents the amount of braking force (expressed as power) in addition to the existing road load forces which combine to slow the vehicle. It is expressed in Equation 5-10. By convention, only negative values are calculated for braking.[dd]

Equation 5-10

$$P_{brake} = P_{accel\_reqd} - P_{roadload}$$

P_{accel_reqd} (kW), in represents the total applied deceleration power necessary to slow the vehicle. It is calculated as the vehicle speed, v (in m/s) multiplied by the deceleration force (vehicle mass * required deceleration rate), as shown in Equation 5-11.

Equation 5-11

$$P_{accel\_reqd} = v * m_{ETW} * \frac{dv}{dt}$$

Where:

m_{ETW} (kg) is the mass of the vehicle based on equivalent test weight (ETW)

dv/dt (m/s^2) is the required acceleration/deceleration for the vehicle to match the next point on the vehicle test trace (as recorded at a 10 Hz rate)

$P_{roadload}$ (kW) is the sum of the road load forces (N) as calculated from the experimental vehicle coastdown coefficients, A, B and C. It is calculated in Equation 5-12.

[cc] These calculations assume a "4-bag" FTP schedule, or 2 consecutive UDDS cycles (cold-start UDDS with a 10 minute soak period and a second hot-start UDDS), as is common for testing HEVs for charge balancing purposes.

[dd] All power terms are negative when power is applied to the vehicle (as in braking). Power provided by the vehicle (such as tractive power – in the case of acceleration) would be positive.

Per convention, road load is negative as it always represents a deceleration (resistive) force acting on the vehicle.

Equation 5-12

$$P_{roadload} = -v * \left(A + Bv + Cv^2\right)$$

5.3.4 Pickup Truck Performance Thresholds for Advanced Technology Credits

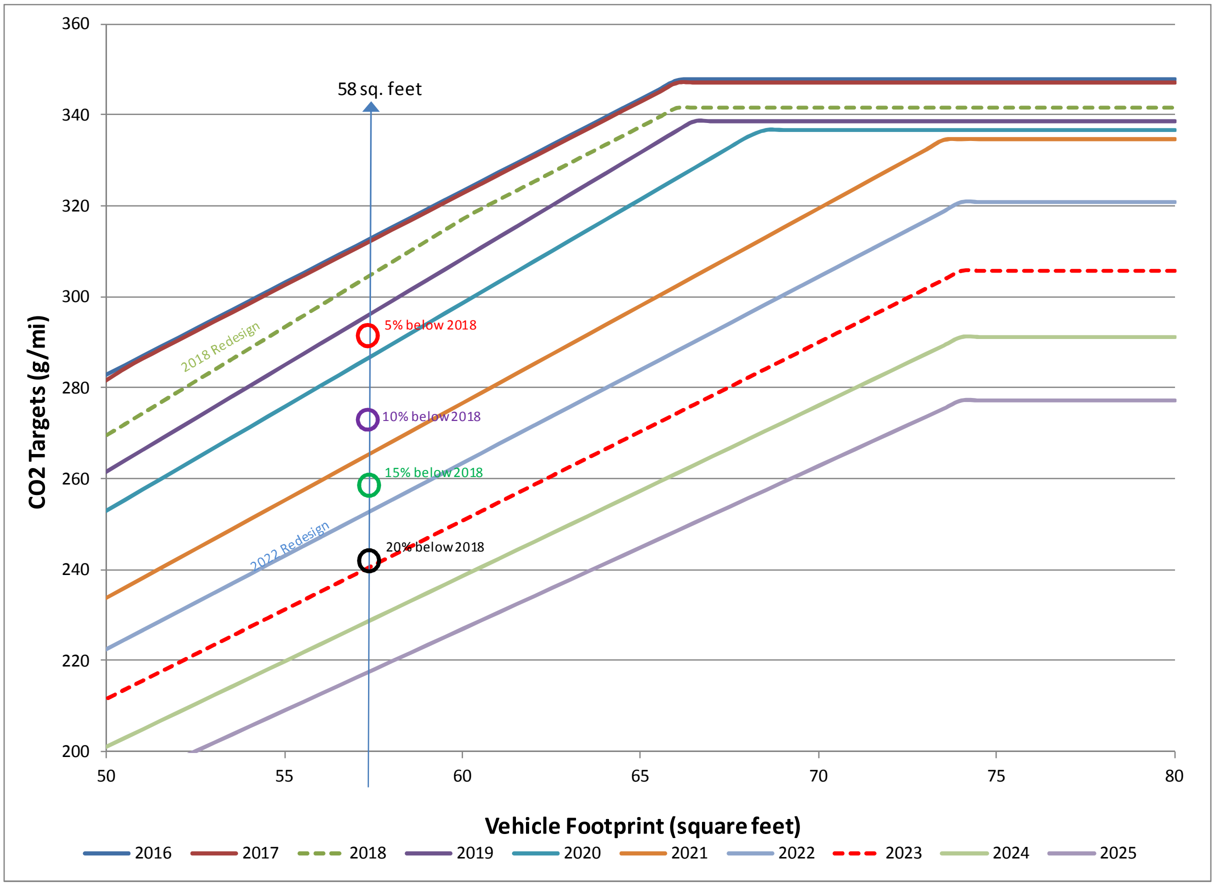
This section describes how the agencies arrived at the threshold values of 15% and 20% better than the footprint target required to qualify a pickup truck for performance-based advanced technology credits.

Based on the lumped parameter model (described in Chapter 3 of this joint TSD), pickup truck hybrids are determined to be approximately 15% more efficient than non-hybrids. However, this can vary over a range of efficiencies depending on the weight, electrification level, HEV architecture, engine/transmission, utility ratings, control strategy, etc. Rather than comparing directly to a given HEV technology, we have instead determined the thresholds based on the year-on-year stringency of the standards (targets). Although we discuss these thresholds in terms of GHG standards, a corresponding analysis could be made based on fuel economy targets.

The targets (curve standards at a given footprint) become more stringent each year. However, a typical vehicle model is redesigned every 5 years (6 years for some larger trucks). When a vehicle model is redesigned, it is assumed that the emissions will not just meet the footprint target, but rather exceed it so that in general the vehicle is generating credits for the first two or three years of the product life, and using credits for the latter two or three years, until the next redesign. Although no individual vehicle is required to meet its footprint target, the manufacturer must meet its fleet obligation based on the footprint and sales volumes of all the light-duty vehicles it produces. Therefore, under normal (business-as-usual) circumstances, each manufacturer will be designing and redesigning some of their vehicle models each year and some vehicles will exceed their targets (for about 2-3 years each) and others will fall short (for about 2-3 years each), thus allowing the manufacturer to average its fleet in order to comply each year. Recognition of this product development cycle is an important element of the program structure.

In the following hypothetical example, illustrated in Figure 5-21, a recently redesigned 58 square foot pickup truck is certified in MY 2018. Its target is 308 g/mi. This truck will not receive another redesign until 2022. Under normal circumstances, a typical vehicle would likely be 10% better than the standard, which would make it a credit generator for three years and a deficit generator for two years (consistent with the usual regulatory strategy outlined in the previous paragraph). At 15% below target (262 g/mi) this truck will generate credits for four years and deficits only in its last year. At 20% below target (246 g/mi), the truck will generate credits for the full five year product development cycle.

Figure 5-21 2017-2025 Truck GHG Standard Curves, with Example Redesign of a 58 square foot truck



The analysis depends somewhat on the footprint selected. Table 5-38 shows the truck footprint targets for each model year for three sample trucks with footprints: 58, 67 and 74 sq ft, and three scenarios: 10%, 15% and 20% better than the target value. The table also shows the number of years each of the sample trucks would take to start generating deficits. In the 10% scenario, the trucks create deficits in 3.4 years on average. In the 15% scenario, it takes 4.7 years and for the 20% scenario it takes 5.7 years on average. Based on this analysis, the agencies have chosen the 15% and 20% thresholds, as these are significantly better than the business-as-usual (~10%) scenario. The performance thresholds of 15% and 20% therefore represent CO_2 reductions greater than what EPA expects companies would typically plan for during a redesign of these products, given the level of the standards and the CO_2 targets for typical full-size pickup trucks. In addition, since the rate of improvement of using hybrid technology on full size pickup trucks is approximately 15% (as noted at the start of this section), this rate of improvement over target is comparable to what would be achieved by applying hybrid technologies to the same vehicles. It is consequently reasonable to provide an equivalent credit amount. These levels are also technically within reach of the companies if they pull ahead technologies which they may not otherwise need until the later years of the program, or in the case of the later years of the program, a pull-ahead of technologies beyond what is needed for MY2025.

Table 5-38: Truck CO2 Footprint Targets for 10%, 15% and 20% Thresholds

	Footprint				**10%** better than std				# of yrs before creating deficits		
	58.0	67.0	74.0		58.0	67.0	74.0		58.0	67.0	74.0
2017	315	347	347	**2017**	283	312	312		4	4	6
2018	308	342	342	**2018**	277	308	308		3	3	5
2019	299	339	339	**2019**	269	305	305		2	3	5
2020	290	331	337	**2020**	261	298	303		2	2	4
2021	268	307	335	**2021**	241	276	301		3	3	3
2022	255	292	321	**2022**	230	263	289		3	3	3
2023	243	278	306	**2023**	219	250	275				
2024	231	265	291	**2024**	208	238	262				
2025	220	252	277	**2025**	198	227	249				
									avg	**3.4**	

	Footprint				**15%** better than std				# of yrs before creating deficits		
Footprint	58.0	67.0	74.0		58.0	67.0	74.0		58.0	67.0	74.0
2017	315	347	347	**2017**	268	295	295		5	5	7
2018	308	342	342	**2018**	262	290	290		4	5	7
2019	299	339	339	**2019**	254	288	288		4	4	6
2020	290	331	337	**2020**	246	281	286		3	3	5
2021	268	307	335	**2021**	228	261	285		4	4	4
2022	255	292	321	**2022**	217	248	273				
2023	243	278	306	**2023**	207	236	260				
2024	231	265	291	**2024**	197	225	247				
2025	220	252	277	**2025**	187	214	236				
									avg	**4.7**	

	Footprint				**20%** better than std				# of yrs before creating deficits		
Footprint	58.0	67.0	74.0		58.0	67.0	74.0		58.0	67.0	74.0
2017	315	347	347	**2017**	252	278	278		6	7	8
2018	308	342	342	**2018**	246	273	273		5	6	
2019	299	339	339	**2019**	239	271	271		5	5	
2020	290	331	337	**2020**	232	265	269		4	5	
2021	268	307	335	**2021**	215	245	268				
2022	255	292	321	**2022**	204	234	257				
2023	243	278	306	**2023**	194	223	244				
2024	231	265	291	**2024**	185	212	233				
2025	220	252	277	**2025**	176	202	222				
									avg	**5.7**	

References:

[1] Schwarz, W., Harnisch, J. 2003, "Establishing Leakage Rates of Mobile Air Conditioners," Prepared for the European Commission (DG Environment), Doc B4-3040/2002/337136/MAR/C1. This document is available in Docket EPA-HQ-OAR-2009-0472-0157.

[2] Vincent, R., Cleary, K., Ayala, A., Corey, R., "Emissions of HFC-134a from Light-Duty Vehicles in California," SAE 2004-01-2256, 2004. This document is available in Docket EPA-HQ-OAR-2009-0472-0186.

[3] EPA, 2009, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007," http://www.epa.gov/climatechange/emissions/usinventoryreport.html. This document is available in Docket EPA-HQ-OAR-2009-0472.

[4] General Motors Press Release, "GM First to Market Greenhouse Gas-Friendly Air Conditioning Refrigerant in U.S.," July 23, 2010.

[5] Malvicino, C., Seccardini, R,, et al, "B-COOL Project – Ford Ka adn Fiat Panda R-744 MAC Systems," SAE 2009-01-0967, 2009.

[6] Ghodbane, M., Craig, T., Baker, J., "Demonstration of Energy-Efficient Secondary Loop HFC-152a Mobile Air Conditioning System – Final Report," U.S. Environmental Protection Agency Report EP07H001055, http://www.epa.gov/cpd/mac/152a/EPASec%20Loop_07Jan08.pdf.

[7] Ghodbane, M., Baker, J., Kadle, P., "Potential Applications of R-152a Refrigerant in Vehicle Climate Control Part II," SAE 2004-01-0918, 2004.

[8] Peral-Antunez, E., "Recent Experiences in MAC System Development – New Alternative Refrigerant Assessment Technical Update," SAE Alternative Refrigerant System Efficiency Symposium, Scottsdale, AZ, September 28, 2011.

[9] Li, X., "Alternative Refrigerant AC6 Performance Evaluation and Optimization Potential," SAE Alternative Refrigerant System Efficiency Symposium, Scottsdale, AZ, September 28, 2011.

[10] Society of Automotive Engineers Surface Vehicle Standard J2727, issued August, 2008, http://www.sae.org. This document is available in Docket EPA-HQ-OAR-2009-0472-0160.

[11] State of California, Manufacturers Advisory Correspondence MAC #2009-01, "Implementation of the New Environmental Performance Label," http://www.arb.ca.gov/msprog/macs/mac0901/mac0901.pdf. This document is available in Docket EPA-HQ-OAR-2009-0175.

[12] State of Minnesota, "Reporting Leakage Rates of HFC-134a from Mobile Air Conditioners," http://www.pca.state.mn.us/climatechange/mac-letter-082908.pdf. This document is available in Docket EPA-HQ-OAR-2009-0472-0178.

[13] Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, "Transportation Energy Data Book: Edition 27," 2008. This document is available in Docket EPA-HQ-OAR-2009-0472

[14] EPA, "Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates - Final Technical Support Document," 179 pp, 2.1MB, EPA420-R-06-017, December, 2006. This document is available in Docket EPA-HQ-OAR-2009-0472.

[15] Ikegama, T., Kikuchi, K., "Field Test Results and Correlation with SAEJ2727," Proceedings of the SAE 7th Alternative Refrigerant Systems Symposium, 2006. This document is available in Docket EPA-HQ-OAR-2009-0472.

[16] Atkinson, W., Baker, J., Ikegami, T., Nickels, P., "Revised SAEJ2727: SAE Interior Climate Control Standards Committee Presentation to the European Commission," 2006. This document is available in Docket EPA-HQ-OAR-2009-0472.

[17] Burnette, A., Baker, R., "A Study of R134a Leaks in Heavy Duty Equipment," CARB Contract No. 06-342, http://www.arb.ca.gov/research/seminars/baker3/baker3.pdf.

[18] Society of Automotive Engineers, "IMAC Team 1 – Refrigerant Leakage Reduction, Final Report to Sponsors," 2006. This document is available in Docket EPA-HQ-OAR-2009-0472-0188.

[19] Minnesota Pollution Control Agency, "Model Year 2009 Leakage Rate List," http://www.pca.state.mn.us/climatechange/mobileair.html. This document is available in Docket EPA-HQ-OAR-2009-0472-0161.

[20] Society of Automotive Engineers, "IMAC Team 4 – Reducing Refrigerant Emissions at Service and Vehicle End of Life," June, 2007. This document is available in Docket EPA-HQ-OAR-2009-0472.

[21] Schwarz, W., "Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems," Study conducted for the German Federal Environmental Office, September, 2001. This document is available in Docket EPA-HQ-OAR-2009-0472.

[22] "A/C Triage – Ensuring Replacement Compressor Survival, " AC Delco Tech Connect, Volume 12, Number 5, January/February, 2005, http://www.airsept.com/Articles/CompressorGuard/ACDelcoTechConnectJanFeb05.pdf. This document is available in Docket EPA-HQ-OAR-2009-0472-0167. This document is available in Docket EPA-HQ-OAR-2009-0472-0167.

[23] Johnson, V., "Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach," SAE 2002-01-1957, 2002. This document is available in Docket EPA-HQ-OAR-2009-0472-0179.

[24] Rugh, J., Johnson, V., Andersen, S., "Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning," Mobile Air Conditioning Summit, Washington DC., April 14-15, 2004. This document is available in Docket EPA-HQ-OAR-2009-0472-0179.

[25] California Environmental Protection Agency Air Resources Board, "STAFF REPORT: Initial statement of reasons for proposed rulemaking, public hearing to consider adoption of regulations to control greenhouse gas emissions from motor vehicles," 2004. This document is available in Docket EPA-HQ-OAR-2009-0472.

[26] "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," Northeast States Center for a Clean Air Future, September, 2004. This document is available in Docket EPA-HQ-OAR-2009-0472.

[27] Lee, S., Lee, B., Zheng, H., Sze, C., Quinones, L., and Sanchez, J., "Development of Greenhouse Gas Emissions Model for 2014-2017 Heavy- and Medium-Duty Vehicle Compliance," SAE 2011 Commercial Vehicle Engineering Congress, Chicago, September 2011, SAE Paper 2011-01-2188.

[28] Forrest, W.O., "Air Conditioning and Gas Guzzler Tax Credits," Society of Automotive Engineers, International Congress & Exposition, Detroit, Michigan, March 2002, SAE Paper 2002-01-1958.

[29] Forrest, W.O. and Bhatti, M.S., "Energy Efficient Automotive Air Conditioning System," Society of Automotive Engineers, International Congress & Exposition, Detroit, Michigan, March 2002, SAE Paper 2002-01-0229.

[30] Johnson, V.H., "Fuel Used for Vehicle Air Condition: A State-by-State Thermal Comfort-Based Approach," Society of Automotive Engineers, International Congress & Exposition, Detroit, Michigan, March 2002, SAE Paper 2002-01-1957.

[31] Rugh, J.P., Hovland, V., Andersen, S.O., "Significant Fuel Savings and Emissions Reductions by Improving Vehicle Air Conditioning," Presentation at the 15th Annual Earth Technologies Forum and Mobile Air Conditioning Summit, April 15, 2004.

[32] Northeast States Center for a Clean Air Future, "Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles," September, 2004.

[33] EPA and DOT, "Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards: Final Rule," May 7, 2010.

[34] Society of Automotive Engineers, "IMAC Team 2 – Improved Efficiency, Final Report," April 2006.

[35] Memo to docket, "Meeting with Delphi and Presentation to EPA," March, 2009. This document is available in Docket EPA-HQ-OAR-2009-0472-0196.

[36] Society of Automotive Engineers Surface Vehicle Standard J2765, issued October, 2008, http://www.sae.org. This document is available in Docket EPA-HQ-OAR-2009-0472-0171.

[37] Barbat, T. et. Al., "CFD Study of Phase Separators in A/C Automotive Systems," SAE 2003-01-0736, 2003. This document is available in Docket EPA-HQ-OAR-2009-0472-0187.

[38] Memo to docket, "Idle Test Data Submitted by USCAR to EPA," July, 2011.

[39] U.S. EPA, "Project Report: Computer Simulation of Light-Duty Vehicle Technologies for Greenhouse Gas Emission Reduction in the 2020-2025 Timeframe", Contract No. EP-C-11-007, Work Assignment 0-12, Docket ID: EPA-HQ-OAR-2010-0799, Document ID: EPA-HQ-OAR-2010-0799-1144

[40] Bradfield, M., "Improving Alternator Efficiency Measurably Reduces Fuel Costs", Remy, Inc., 2008.

[41] Schoettle, B., et al., "LEDS and Power Consumption of Exterior Automotive Lighting: Implications for Gasoline and Electric Vehicles," University of Michigan Transportation Research Institute, October, 2008.

[42] American Honda Motor Co. comments, NHTSA Docket ID# NHTSA-2010-0131-0239, EPA Docket ID# EPA-HQ-OAR-2010-0799-9489.

[43] State of California Air Resources Board, Draft Manufacturer's Advisory Correspondence – Optional Test Procedure for Certifying Model-Year 2016 and Later Vehicles Under the Cool Cars Alternative Performance Compliance Option, March 3, 2010.

[44] Rugh, J., Farrington, R. "Vehicle Ancillary Load Reduction Project Close-Out Report," National Renewable Energy Laboratory Technical Report NREL/TP-540-42454, January, 2008.

[45] Rugh, J., et al., "Reduction in Vehicle Temperatures and Fuel Use from Cabin Ventilation, Solar-Reflective Paint, and New Solar-Reflective Glazing," SAE 2007-01-1194, 2007.

[46] EPA Technical Memorandum from James Sanchez and Ben Ellies, May 21, 2012: "Energy Recovery Testing for GM Silverado 2-Mode Hybrid and Other Hybrid Light-duty Vehicles".

[47] EPA e-mail memorandum from Ben Ellies to Don Kopinski, May 23, 2012, "Data for GM 2-mode hybrid pickup truck".

[48] E-mail correspondence from James Sanchez to Eric Rask, May 3, 2012.

[49] EPA memorandum from James Sanchez to Docket EPA-HQ-OAR-2010-0799, July 23, 2012: “Analysis of ANL’s HEV Data to Evaluate Methods for Determining Nominal Voltage”.