APPENDIX G

NHTSA Preliminary Regulatory Impact Analysis

U.S. Department
Of Transportation
National Highway
Traffic Safety Administration

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Preliminary Regulatory Impact Analysis

Corporate Average Fuel Economy for MY 2017-MY 2025 Passenger Cars and Light Trucks

Office of Regulatory Analysis and Evaluation
National Center for Statistics and Analysis

November 2011

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EXECUTIVE SUMMARY

This Preliminary Regulatory Impact Analysis (PRIA) has been prepared by the National Highway Traffic Safety Administration (NHTSA) to inform the agency's consideration of proposed Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks for model years (MYs) 2017 through 2025. NHTSA is required to set CAFE standards by the Energy Policy and Conservation Act of 1975 (EPCA), as amended by the Energy Independence and Security Act of 2007 (EISA). NHTSA does not have discretion not to set CAFE standards each model year for passenger cars and light trucks. CAFE standards must be set at least 18 months prior to the beginning of the model year; must be "attribute-based and defined by a mathematical function;" and must be set at the maximum feasible level that NHTSA determines manufacturers can reach for that fleet in that model year, among other requirements. *See* 49 U.S.C.

32902 and Section IV.D of the preamble that this PRIA accompanies for more information.

This assessment examines the costs and benefits of improving the fuel economy of passenger cars and light trucks for MYs 2017-2025, and also the costs and benefits of improving the fuel economy of those vehicles at alternative rates of increase (both higher and lower) during those model years. As part of that examination, it includes a discussion of the technologies that can improve fuel economy, analysis of the potential impact on retail prices, safety, lifetime fuel savings and their value to consumers, and other societal benefits such as improved energy security and reduced emissions of pollutants and greenhouse gases.[1]

As explained above, EISA requires NHTSA to set attribute-based CAFE standards that are based on a mathematical function. The MY 2017-2025 CAFE standards for passenger cars and light trucks are based on vehicle footprint, as were the standards for MYs 2012-2016.[2] The mathematical function or "curve" representing the footprint-based standards is a constrained linear function that provides a separate fuel economy target for each vehicle footprint, generally with more stringent targets for smaller vehicles and less stringent targets for larger vehicles. Different parameters for the continuous mathematical function are derived. Individual manufacturers will be required to comply with a single fuel economy level that is based on the distribution of its production for that year among the footprints of its vehicles. Although a manufacturer's compliance obligation is determined in the same way for both passenger cars and light trucks, the footprint target curves for the different fleets are established with different continuous mathematical functions that are intended to be specific to the vehicles' design capabilities, to reflect the statutory requirement that the standards are supposed to be "maximum feasible" for each fleet separately.

In order to evaluate the costs and benefits of the rule, a baseline prediction of the fuel economy and mix of vehicles that would be sold in MYs 2017 to 2025 in the absence of the proposed new standards was constructed. As was done for the MY 2012-2016 final rule, a baseline was developed using each manufacturer's MY 2008 fleet as represented in CAFE certification data available to EPA. In order to conduct this analysis, we assume that similar vehicles will be produced through MY 2025 and technologies are added to this baseline fleet to determine what mpg levels could be achieved by the manufacturers in the MYs 2017-2025 timeframe. The main analysis includes a "flat" baseline, for which we assume that manufacturers would have made no fuel economy improvements above the MY 2016 CAFE standards. In the sensitivity analysis section, we examine an alternative baseline, for which we assume that manufacturers would meet market demand for slightly higher fuel economy levels in

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[1] This analysis does not contain NHTSA's assessment of the potential environmental impacts of the final rule for purposes of the National Environmental Policy Act (NEPA), 42 U.S.C. 4321-4347, which is contained in the agency's Draft Environmental Impact Statement (DEIS) accompanying the proposed rule.

[2] Vehicle Footprint is defined as the wheelbase (the distance from the center of the front axle to the center of the rear axle) times the average track width (the distance between the centerline of the tires) of the vehicle (in square feet).

light of higher real prices of fuel and given the new fuel economy labeling rule that was promulgated earlier this year and would supply technologies that have a consumer payback (defined by fuel savings exceed retail price increases) in one year or less. NHTSA seeks comment on which of these baselines is a better prediction of what would occur if the proposed rule were not adopted, or whether the baseline should include a more fuel efficient mix of vehicles that incorporates all fuel economy improvements that consumers value more than they cost.

NHTSA has examined nine alternatives, including six that are defined as annual percentage improvements over the baseline – 2%/year, 3%/year, 4%/year, 5%/year, 6%/year, and 7%/year. In addition to those six are what NHTSA has called the " Preferred Alternative," which represents the standards that the agency is proposing for MYs 2017-2025; the " Maximum Net Benefits" alternative, which Executive Orders 12866 and 13563 encourage the agency to choose unless statutory considerations mandate otherwise; and the " Total Costs Equal Total Benefits" alternative. Looking at the " required" mpg levels in Table 3a and 3b, the " Preferred Alternative" for passenger cars would require fuel economy levels that are generally between the 3 and 4 percent annual increase alternatives, although the percentage increase varies from year to year. The " Preferred Alternative" for light trucks starts at less than the 2% alternative in MY 2017 and increases to between the 3 and 4 percent alternative in MY 2025. The " Maximum Net Benefits" alternative is based upon the agency's assessment of the availability of technologies and a marginal cost/benefit analysis. In this case the agency continues to include additional technologies in its analysis until the marginal cost of adding the next technology exceeds the marginal benefit. The "Maximum Net Benefits" alternative maximizes net benefits for each year for 9 consecutive years, but it does not maximize benefits over all 9 years together. The "Maximum Net Benefit" for passenger cars would require levels that are higher than the "Preferred Alternative" in MYs 2017 through 2022, but then falls below the preferred alternative levels in MY 2023-25. The "Maximum Net Benefit" required mpg level for light trucks is higher in every year than the levels in the "Preferred Alternative." The "Total Costs Equal Total Benefits" alternative represents an increase in the standard to a point where essentially total costs of the technologies added together over the baseline added equals total benefits over the baseline. In this analysis, for brevity, at times it is labeled "TC = TB." The "TC = TB" levels are higher than the "Preferred" alternative levels in all years.

The agency performed a variety of sensitivity analyses to examine the variability of the CAFE model's results to certain economic assumptions. Sensitivity analyses were performed on the following:

1) The price of gasoline: The main analysis uses the Reference Case AEO 2011 estimate for the price of gasoline; we study the effect of using the AEO 2011 Low and High Price Cases on the model results.
2) The rebound effect: The main analysis uses a rebound effect of 10 percent to project increased miles traveled as the cost per mile decreases. In the sensitivity analysis, we examine the effect of using a 5, 15, or 20 percent rebound effect.
3) The value of CO_2 benefits: The main analysis uses an initial value of $22 per ton to quantify the benefits of reducing CO_2 emissions. Sensitivity analysis

surrounding this assumption considers the use of alternate base values of \$5, \$36, and \$67.[3]

4) The military security component: The main analysis does not assign a value to the military security benefits of reducing fuel consumption. In the sensitivity analysis, we examine the impact of using a value of 12 cents per gallon instead.
5) Consumer benefit: The main analysis assumes there is no loss in value to consumers resulting from vehicles that have an increase in price and higher fuel economy. This sensitivity analysis assumes that there is a 25, or 50 percent loss in value to consumers – equivalent to the assumption that consumers will only value the calculated benefits they will achieve at 75, or 50 percent, respectively, of the main analysis estimates.
6) ICM and RPE cost methods: The main analysis uses the ICM cost method with an overall markup factor from variable cost to equivalent retail price of 1.2 to 1.25. The retail price equivalent (RPE) cost method results in higher cost estimates for each of the technologies, as it uses a markup factor of 1.5. A sensitivity analysis involving the RPE method was conducted. The agency also performed a sensitivity analysis using the ICM method, but with NAS estimates of technology costs.
7) Technology costs with NAS cost estimates: The agency conducted a sensitivity analysis using values that were derived from the 2011 NAS report.[4] This analysis used a RPE markup factor of 1.5 for non-electrification technologies, which is consistent with the NAS estimation for technologies manufactured by suppliers, and a RPE markup factor of 1.33 for electrification technologies (HEV, PHEV and EV); three types of learning which include no learning for mature technologies, 1.25 percent annual learning for evolutionary technologies, and 2.5 percent annual learning for revolutionary technologies; technology cost estimated for 52 percent (33 out of 63) technologies; and technology effectiveness estimates for 56 percent (35 out of 63) of technologies. Cost learning was applied to technology costs in a manner similar to how cost learning is applied in the central analysis for many technologies which have base costs which are applicable to recent or near-term future model years. As noted above, the cost learning factors used for the sensitivity case are different than the values used in the central analysis. For the other inputs in the sensitivity case, where the NAS study has inconsistent information or lacks projections, NHTSA used the same inputs NHTSA used in the central analysis.
8) Battery cost: The agency conducted a sensitivity analysis of battery costs in relation to HEV, PHEV, and EV batteries. For HEV batteries, a sensitivity analysis was performed with a +/- 10 percent variation in cost per kWh, while sensitivity analyses involving PHEV and EV batteries utilized alternate ranges contingent on the type of battery cathode (see chapter X for additional detail).

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[3] These values are rounded to the nearest dollar; the values used in the sensitivity analysis are unrounded. The unrounded values are presented in Chapter X.

[4] 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 November 13, 2011)

PHEV and EV battery costs ranged between -20 percent and +35 percent in this sensitivity analysis.

9) Mass reduction cost: A sensitivity analysis was performed examining the impact of vehicle mass reduction that could feasibly be accomplished with a +/- 40 percent impact on vehicle cost.

The agency also performed a probabilistic uncertainty analysis on the model results of the proposed preferred alternative, as mandated by OMB Circular A-4. Over all nine MYs (2017-2025), the higher CAFE standards will produce a net impact ranging from a net cost of $141.4 billion to a net benefit of $703.0 billion. Across all model years, each model year's passenger car fleet has, at minimum, an 89.2 percent certainty that higher CAFE standards will produce a net benefit. For light truck fleets, this value is 98.6 percent. The uncertainty analysis is presented in detail in Chapter XII.

The MYs 2017-2025 proposed CAFE standards, like the MYs 2012-2016 CAFE standards, are being proposed jointly with the Environmental Protection Agency (EPA), which is concurrently proposing greenhouse gas (GHG) standards for the same vehicles for the same model years. The joint proposal would extend the National Program established for MYs 2012-2016 for these additional future model years. In working together to develop the next round of standards for MYs 2017-2025, NHTSA and EPA are building on the success of the first phase of the National Program to regulate fuel economy and GHG emissions from U.S. light-duty vehicles, which established the strong and coordinated standards for model years (MY) 2012-2016. As for the MYs 2012-2016 rulemaking, collaboration with California Air Resources Board (CARB) and with industry and other stakeholders has been a key element in developing the agencies' proposed rules. Continuing the National Program would ensure that all manufacturers can build a single fleet of U.S. vehicles that would satisfy all requirements under both programs as well as under California's program, helping to reduce costs and regulatory complexity while providing significant energy security and environmental benefits. The coordinated program being proposed would achieve important reductions of fuel consumption and GHG emissions from passenger cars and light trucks, based on technologies that either are commercially available or that the agencies project will be commercially available in the rulemaking timeframe and that can be incorporated at a reasonable cost. Consistent with Executive Order 13563, this proposal was developed with early consultation with stakeholders, employs flexible regulatory approaches to reduce burdens, maintains freedom of choice for the public, and helps to harmonize federal and state regulations. Because the agencies are collaborating on the National Program, however, it is important to note throughout this analysis that there is significant overlap in costs and benefits for NHTSA's CAFE program and EPA's GHG program, and therefore combined program costs and benefits are not a sum of the two individual programs.

Table 1 presents the total costs (technology and social), benefits, and net benefits for NHTSA's proposed CAFE levels by alternative. The values in Table 1 display the total costs for all MY 2017-2025 vehicles and the benefits and net benefits represent the impacts of the standards over the full lifetimes of the vehicles projected to be sold during model years 2017 – 2025.

Table 1

NHTSA's Estimated 2017-2025 Model Year Costs, Benefits, and Net Benefits[5] under the Preferred Alternative CAFE Standards
(Billions of 2009 Dollars)

3% Discount Rate	
Costs	$177.6
Benefits	$521.8
Net Benefits	$344.2
7% Discount Rate	
Costs	$168.6
Benefits	$424.0
Net Benefits	$255.4

Table 2 shows the overall analysis summary of costs, benefits, and net benefits for the nine model years by alternative for the combined light duty fleet. Table 4 shows the agency' s projection of the estimated actual harmonic average that would be achieved by the manufacturers, assuming that some manufacturers will pay fines rather than meet the required levels. Table 3 shows the estimated required levels. All of the tables in this analysis compare the flat MY 2016 baseline to the projected achieved harmonic average. Additionally all of the tables in the Executive Summary and in the analysis as a whole use the central value for the Social Cost of Carbon (SCC), which is the average SCC across models at the 3 percent discount rate. The SCC is discussed in more detail in Chapter VIII. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range of SCC values.

Costs: Costs were estimated based on the specific technologies that were applied to improve each manufacturer' s fuel economy up to their achieved level under each alternative or fines that would be assessed. Table 5 provides the cost and fine estimates on an average per-vehicle basis, and Table 6 provides those estimates (including social costs and excluding fines) on a fleet-wide basis in millions of dollars.

Benefits: Benefits are determined mainly from fuel savings over the lifetime of the vehicle, but also include externalities such as reductions in criteria pollutants. The agency uses a 3 percent and 7 percent discount rate to value intra-generational future benefits and costs. Inter-generational[6] benefits from future carbon dioxide reductions are discounted at 3 percent in the main analysis, even when intra-generational benefits

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[5] In Table 1, and throughout this regulatory impact analysis, discounting is applied to all costs and benefits with the exception of technology costs.

[6] Inter-generational benefits, which include reductions in the expected future economic damages caused by increased global temperatures, a rise in sea levels, and other projected impacts of climate change, are anticipated to extend over a period from approximately fifty to two hundred or more years in the future, and will thus be experienced primarily by generations that are not now living.

are discounted at 7 percent. Sensitivity analyses in Chapter X consider other inter-generational discount rates that accompany alternative estimates of the social cost of carbon. Table 7 provides those estimates on an industry-wide basis at a 3 percent discount rate and Table 10 provides the estimates at a 7 percent discount rate.

Net Benefits: Tables 8 and 11 compare total net benefits of each alternative at the 3 percent and 7 percent discount rates, respectively.

Fuel Savings: Tables 12a through 12c show the lifetime fuel savings in millions of gallons.

Change in Electricity Consumption: Tables 12d through 12f show the lifetime net change in electrical consumption, in gigawatt-hours.

Table 2
Total Costs, Benefits, and Net Benefits
Passenger Cars and Light Trucks
MY 2017-2025 Combined
(Millions of 2009 Dollars)

	3% Discount Rate		
	Costs	Benefits	Net Benefits
Preferred Alternative	$177,579	$521,818	$344,239
2% Annual Increase	$88,020	$335,246	$247,227
3% Annual Increase	$149,653	$492,767	$343,114
4% Annual Increase	$229,057	$622,223	$393,166
5% Annual Increase	$321,534	$738,940	$417,406
6% Annual Increase	$398,370	$812,452	$414,082
7% Annual Increase	$441,397	$865,036	$423,639
Max Net Benefits	$280,743	$680,178	$399,436
Total Cost = Total Benefit	$346,613	$768,632	$422,019
	7% Discount Rate		
	Costs	Benefits	Net Benefits
Preferred Alternative	$168,563	$423,961	$255,399
2% Annual Increase	$82,201	$272,101	$189,900
3% Annual Increase	$141,196	$399,948	$258,751
4% Annual Increase	$218,471	$504,750	$286,279
5% Annual Increase	$308,881	$599,605	$290,725
6% Annual Increase	$384,088	$659,091	$275,003
7% Annual Increase	$426,176	$701,740	$275,565
Max Net Benefits	$238,380	$513,724	$275,344
Total Cost = Total Benefit	$325,725	$616,689	$290,964

Table 3a
Alternative CAFE Levels
Estimated Required Average for the Passenger Car Fleet, in mpg[7]

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars									
Preferred Alternative	40.0	41.4	43.0	44.7	46.6	48.8	51.0	53.5	56.0
2% Annual Increase	39.4	40.2	41.1	41.9	42.8	43.7	44.6	45.5	46.5
3% Annual Increase	39.8	41.1	42.4	43.7	45.1	46.5	48.0	49.5	51.1
4% Annual Increase	40.2	41.9	43.7	45.6	47.5	49.6	51.7	53.9	56.3
5% Annual Increase	40.6	42.8	45.2	47.6	50.2	52.9	55.8	58.8	62.0
6% Annual Increase	41.1	43.8	46.7	49.7	53.0	56.5	60.2	64.2	68.5
7% Annual Increase	41.5	44.8	48.2	51.9	56.0	60.4	65.1	70.2	75.7
Max Net Benefits (3% Discount Rate)	43.6	45.7	46.9	48.1	48.6	48.9	49.4	50.2	50.7
Max Net Benefits (7% Discount Rate)	43.6	45.7	46.9	48.1	48.6	48.9	49.4	50.2	50.7
Total Cost = Total Benefit (3% Discount Rate)	44.8	46.7	48.1	49.6	50.7	53.1	55.0	57.1	58.6
Total Cost = Total Benefit (7% Discount Rate)	44.8	46.7	48.1	49.6	50.7	53.1	55.0	57.1	58.6

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[7] The choice of a 3 or 7 percent discount rate can impact the results of the Max Net Benefits and Total Cost = Total Benefits scenarios. The results of all other scenarios are not impacted by choice of discount rate. Results for both 3 and 7 percent discount rates are therefore presented for both Max Net Benefits and Total Cost = Total Benefit scenarios.

Table 3b
Alternative CAFE Levels
Estimated Required Average for the Light Truck Fleet, in mpg

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	29.4	30.0	30.6	31.2	33.3
2% Annual Increase	30.1	30.8	31.6	32.1	32.8
3% Annual Increase	30.4	31.5	32.6	33.5	34.6
4% Annual Increase	30.6	32.1	33.6	35.0	36.5
5% Annual Increase	30.9	32.8	34.7	36.5	38.5
6% Annual Increase	31.3	33.5	35.8	38.1	40.7
7% Annual Increase	31.6	34.2	37.0	39.8	43.0
Max Net Benefits (3% Discount Rate)	34.0	35.6	37.5	39.8	40.9
Max Net Benefits (7% Discount Rate)	32.8	34.6	36.6	37.6	39.3
Total Cost = Total Benefit (3% Discount Rate)	34.2	36.0	37.9	39.2	40.5
Total Cost = Total Benefit (7% Discount Rate)	34.3	36.0	37.9	39.2	40.5

Alternative	MY 2022	MY 2023	MY 2024	MY 2025
Light Trucks				
Preferred Alternative	34.9	36.6	38.5	40.3
2% Annual Increase	33.5	34.3	35.1	35.8
3% Annual Increase	35.7	36.9	38.2	39.4
4% Annual Increase	38.1	39.8	41.6	43.4
5% Annual Increase	40.6	42.9	45.4	47.9
6% Annual Increase	43.4	46.3	49.5	52.8
7% Annual Increase	46.4	50.1	54.2	58.4
Max Net Benefits (3% Discount Rate)	41.8	43.0	44.2	47.3
Max Net Benefits (7% Discount Rate)	39.7	40.2	40.7	41.2
Total Cost = Total Benefit (3% Discount Rate)	41.1	43.4	45.4	46.6
Total Cost = Total Benefit (7% Discount Rate)	41.1	43.4	45.4	46.6

Table 3c
Alternative CAFE Levels
Estimated Required Average for the Combined Fleet, in mpg

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars & Light Trucks									
Preferred Alternative	35.3	36.4	37.5	38.8	40.9	42.9	45.0	47.3	49.6
2% Annual Increase	35.4	36.2	37.1	37.9	38.7	39.5	40.4	41.4	42.3
3% Annual Increase	35.7	37.0	38.2	39.5	40.8	42.1	43.5	45.0	46.5
4% Annual Increase	36.1	37.7	39.4	41.2	43.0	44.9	46.9	49.1	51.2
5% Annual Increase	36.4	38.5	40.7	43.0	45.4	47.9	50.6	53.5	56.5
6% Annual Increase	36.8	39.4	42.1	44.9	47.9	51.1	54.6	58.4	62.4
7% Annual Increase	37.2	40.3	43.5	46.9	50.6	54.6	59.0	63.8	69.0
Max Net Benefits (3% Discount Rate)	39.5	41.4	43.0	44.8	45.6	46.2	47.0	48.0	49.5
Max Net Benefits (7% Discount Rate)	38.9	40.9	42.6	43.8	44.9	45.2	45.8	46.5	47.1
Total Cost = Total Benefit (3% Discount Rate)	40.2	42.1	43.9	45.4	46.6	48.2	50.4	52.5	54.0
Total Cost = Total Benefit (7% Discount Rate)	40.3	42.1	43.9	45.4	46.6	48.2	50.4	52.5	54.0

Table 3d
Estimated Required Preferred Alternative CAFE Levels
Projected Required Average for the Fleet, in gallons per 100 miles

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	2.5018	2.4129	2.3258	2.2390	2.1453
Light Trucks	3.4001	3.3285	3.2707	3.2037	2.9994
Combined	2.8325	2.7462	2.6644	2.5791	2.4452
		MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars		2.0493	1.9590	1.8705	1.7869
Light Trucks		2.8637	2.7286	2.5994	2.4795
Combined		2.3319	2.2218	2.1148	2.0161

Table 4a
Alternative CAFE Levels
Projected Achieved Harmonic Average for the Passenger Car Fleet, in mpg[8]

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars									
Preferred Alternative	38.8	40.6	42.7	44.6	46.1	47.2	48.8	50.5	52.7
2% Annual Increase	38.1	39.4	40.6	41.8	42.7	43.3	43.8	44.5	45.1
3% Annual Increase	38.5	40.3	42.0	43.7	44.9	45.9	46.7	47.8	49.2
4% Annual Increase	39.1	41.1	43.2	45.4	46.8	47.8	49.0	51.0	52.8
5% Annual Increase	39.8	42.1	44.4	46.9	49.1	50.1	51.7	55.2	57.5
6% Annual Increase	40.5	43.0	45.4	48.4	50.1	51.2	53.2	57.9	61.0
7% Annual Increase	40.9	43.6	46.1	49.2	50.6	52.4	55.4	59.6	62.9
Max Net Benefits (3% Discount Rate)	41.4	42.8	44.7	46.0	47.1	47.4	48.0	48.5	49.2
Max Net Benefits (7% Discount Rate)	41.3	42.7	44.6	46.0	47.0	47.4	47.8	48.4	49.1
Total Cost = Total Benefit (3% Discount Rate)	42.1	43.7	45.3	46.9	48.7	50.2	52.1	53.9	55.6
Total Cost = Total Benefit (7% Discount Rate)	42.1	43.7	45.3	46.8	48.6	49.5	51.6	53.4	55.0

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[8] The choice of a 3 or 7 percent discount rate can impact the results of the Max Net Benefits and Total Cost = Total Benefits scenarios. The results of all other scenarios are not impacted by choice of discount rate. Results for both 3 and 7 percent discount rates are therefore presented for both Max Net Benefits and Total Cost = Total Benefit scenarios.

Table 4b
Alternative CAFE Levels
Projected Achieved Harmonic Average for the Light Truck Fleet, in mpg

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Light Trucks									
Preferred Alternative	29.0	30.1	31.8	33.0	34.8	35.5	36.3	37.4	38.6
2% Annual Increase	29.4	30.3	31.7	32.4	33.4	33.7	34.2	34.7	35.0
3% Annual Increase	29.7	31.1	32.7	33.9	35.3	36.1	36.6	37.5	38.4
4% Annual Increase	30.2	31.8	33.9	35.4	37.2	38.2	39.3	40.2	41.6
5% Annual Increase	30.7	32.4	34.7	36.6	38.7	39.8	40.9	42.8	44.4
6% Annual Increase	31.3	33.1	35.8	37.9	39.5	40.6	41.8	43.5	45.3
7% Annual Increase	31.6	33.5	36.2	38.3	39.7	41.4	42.8	44.9	46.0
Max Net Benefits (3% Discount Rate)	32.5	33.7	35.6	37.2	39.0	39.5	40.7	42.2	43.9
Max Net Benefits (7% Discount Rate)	31.9	33.1	35.0	36.2	38.0	38.5	39.3	39.8	40.1
Total Cost = Total Benefit (3% Discount Rate)	32.5	33.7	35.6	37.2	39.0	39.6	41.0	42.5	44.4
Total Cost = Total Benefit (7% Discount Rate)	32.6	33.7	35.6	37.2	39.0	39.6	41.0	42.5	44.4

Table 4c
Alternative CAFE Levels
Projected Achieved Harmonic Average for the Combined Fleet, in mpg

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars & Light Trucks					
Preferred Alternative	34.5	36.0	38.0	39.7	41.4
2% Annual Increase	34.4	35.5	36.9	37.9	38.9
3% Annual Increase	34.7	36.4	38.2	39.7	41.0
4% Annual Increase	35.3	37.1	39.3	41.3	42.9
5% Annual Increase	35.9	38.0	40.4	42.6	44.8
6% Annual Increase	36.5	38.8	41.4	44.1	45.8
7% Annual Increase	36.9	39.3	42.0	44.7	46.1
Max Net Benefits (3% Discount Rate)	37.6	39.0	41.0	42.5	43.9
Max Net Benefits (7% Discount Rate)	37.3	38.6	40.7	42.0	43.4
Total Cost = Total Benefit (3% Discount Rate)	38.0	39.5	41.3	42.9	44.8
Total Cost = Total Benefit (7% Discount Rate)	38.0	39.5	41.3	42.9	44.8

Alternative	MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars & Light Trucks				
Preferred Alternative	42.4	43.7	45.2	47.0
2% Annual Increase	39.4	40.0	40.7	41.2
3% Annual Increase	41.9	42.7	43.7	45.0
4% Annual Increase	44.0	45.2	46.8	48.5
5% Annual Increase	46.0	47.4	50.3	52.4
6% Annual Increase	46.9	48.7	52.1	54.7
7% Annual Increase	47.9	50.3	53.7	56.1
Max Net Benefits (3% Discount Rate)	44.4	45.2	46.2	47.3
Max Net Benefits (7% Discount Rate)	43.9	44.5	45.2	45.7
Total Cost = Total Benefit (3% Discount Rate)	45.9	47.7	49.5	51.3
Total Cost = Total Benefit (7% Discount Rate)	45.5	47.4	49.2	51.0

Table 4d
Preferred Alternative CAFE Levels
Projected Achieved Harmonic Average for the Fleet, in gallons per 100 miles

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars	2.5792	2.4649	2.3445	2.2425	2.1714	2.1188	2.0482	1.9788	1.8960
Light Trucks	3.4483	3.3220	3.1429	3.0347	2.8735	2.8136	2.7553	2.6719	2.5898
Combined	2.8991	2.7770	2.6306	2.5218	2.4179	2.3599	2.2897	2.2111	2.1256

Table 5a
Average Incremental Technology Costs or Fines Per Vehicle[9]
Passenger Cars (2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars									
Preferred Alternative	$151	$342	$563	$812	$1,041	$1,203	$1,520	$1,803	$2,040
2% Annual Increase	$60	$155	$257	$353	$431	$502	$552	$642	$693
3% Annual Increase	$103	$270	$438	$622	$778	$894	$1,010	$1,159	$1,343
4% Annual Increase	$216	$447	$683	$961	$1,175	$1,323	$1,568	$1,950	$2,101
5% Annual Increase	$378	$682	$939	$1,278	$1,719	$1,928	$2,241	$3,117	$3,103
6% Annual Increase	$549	$940	$1,243	$1,708	$2,034	$2,373	$2,897	$4,207	$4,086
7% Annual Increase	$637	$1,086	$1,409	$1,926	$2,243	$2,757	$3,691	$4,813	$4,746
Max Net Benefits (3% Discount Rate)	$684	$837	$1,166	$1,274	$1,346	$1,355	$1,408	$1,463	$1,433
Max Net Benefits (7% Discount Rate)	$677	$832	$1,158	$1,267	$1,339	$1,348	$1,387	$1,457	$1,435
Total Cost = Total Benefit (3% Discount Rate)	$873	$1,090	$1,243	$1,405	$1,638	$2,049	$2,490	$2,847	$2,722
Total Cost = Total Benefit (7% Discount Rate)	$873	$1,090	$1,237	$1,402	$1,632	$1,838	$2,316	$2,698	$2,616

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[9] The choice of a 3 or 7 percent discount rate can impact the results of the Max Net Benefits and Total Cost = Total Benefits scenarios. The results of all other scenarios are not impacted by choice of discount rate. Results for both 3 and 7 percent discount rates are therefore presented for both Max Net Benefits and Total Cost = Total Benefit scenarios.

Table 5b
Average Incremental Technology Costs or Fines Per Vehicle
Light Trucks (2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$57	$180	$362	$528	$767
2% Annual Increase	$117	$210	$325	$403	$480
3% Annual Increase	$190	$336	$487	$681	$871
4% Annual Increase	$319	$536	$846	$1,203	$1,524
5% Annual Increase	$473	$790	$1,188	$1,663	$2,124
6% Annual Increase	$740	$1,150	$1,625	$2,225	$2,540
7% Annual Increase	$903	$1,309	$1,771	$2,382	$2,646
Max Net Benefits (3% Discount Rate)	$1,307	$1,475	$1,686	$2,056	$2,319
Max Net Benefits (7% Discount Rate)	$1,057	$1,220	$1,449	$1,640	$1,891
Total Cost = Total Benefit (3% Discount Rate)	$1,305	$1,481	$1,689	$2,051	$2,329
Total Cost = Total Benefit (7% Discount Rate)	$1,315	$1,485	$1,694	$2,055	$2,322

Alternative	MY 2022	MY 2023	MY 2024	MY 2025
Light Trucks				
Preferred Alternative	$877	$997	$1,169	$1,384
2% Annual Increase	$517	$573	$636	$661
3% Annual Increase	$982	$1,069	$1,202	$1,344
4% Annual Increase	$1,690	$1,953	$2,109	$2,356
5% Annual Increase	$2,353	$2,653	$3,314	$3,467
6% Annual Increase	$2,832	$3,250	$3,854	$4,048
7% Annual Increase	$3,267	$3,743	$4,525	$4,450
Max Net Benefits (3% Discount Rate)	$2,424	$2,736	$3,147	$3,419
Max Net Benefits (7% Discount Rate)	$1,930	$2,026	$2,118	$2,032
Total Cost = Total Benefit (3% Discount Rate)	$2,413	$2,845	$3,301	$3,461
Total Cost = Total Benefit (7% Discount Rate)	$2,407	$2,849	$3,309	$3,471

Table 5c
Average Incremental Technology Costs or Fines Per Vehicle
Combined (2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars & Light Trucks									
Preferred Alternative	$117	$283	$491	$712	$945	$1,090	$1,342	$1,591	$1,823
2% Annual Increase	$81	$175	$281	$371	$448	$507	$559	$640	$683
3% Annual Increase	$135	$294	$456	$643	$810	$925	$1,030	$1,173	$1,344
4% Annual Increase	$254	$479	$741	$1,046	$1,297	$1,451	$1,699	$2,003	$2,186
5% Annual Increase	$413	$722	$1,028	$1,414	$1,862	$2,075	$2,381	$3,183	$3,223
6% Annual Increase	$619	$1,016	$1,380	$1,890	$2,212	$2,533	$3,018	$4,089	$4,073
7% Annual Increase	$735	$1,167	$1,539	$2,087	$2,384	$2,934	$3,709	$4,716	$4,648
Max Net Benefits (3% Discount Rate)	$913	$1,070	$1,352	$1,550	$1,688	$1,726	$1,861	$2,027	$2,090
Max Net Benefits (7% Discount Rate)	$817	$973	$1,262	$1,399	$1,533	$1,550	$1,605	$1,679	$1,633
Total Cost = Total Benefit (3% Discount Rate)	$1,032	$1,232	$1,403	$1,633	$1,880	$2,175	$2,611	$2,999	$2,967
Total Cost = Total Benefit (7% Discount Rate)	$1,036	$1,234	$1,401	$1,632	$1,874	$2,035	$2,498	$2,903	$2,899

Table 6a
Incremental Total Costs by Societal Perspective[10], by Alternative
Passenger Cars, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars										
Preferred Alternative	$2,084	$4,438	$7,387	$10,687	$13,646	$15,928	$20,201	$24,329	$28,590	$127,289
2% Annual Increase	$903	$2,175	$3,631	$5,074	$6,270	$7,381	$8,270	$9,772	$10,932	$54,407
3% Annual Increase	$1,501	$3,656	$5,944	$8,496	$10,641	$12,407	$14,188	$16,599	$19,728	$93,159
4% Annual Increase	$2,869	$5,658	$8,722	$12,378	$15,189	$17,338	$20,728	$26,183	$29,272	$138,337
5% Annual Increase	$4,765	$8,300	$11,645	$15,996	$21,485	$24,264	$28,598	$40,437	$42,329	$197,819
6% Annual Increase	$6,720	$11,114	$14,888	$20,745	$24,643	$28,631	$35,382	$54,306	$55,339	$251,768
7% Annual Increase	$7,778	$12,706	$16,630	$22,949	$26,114	$31,378	$43,568	$59,906	$61,921	$282,950
Max Net Benefits	$8,242	$9,939	$13,837	$15,679	$17,108	$17,716	$18,916	$20,233	$20,848	$142,517
Total Cost = Total Benefit	$10,185	$12,707	$14,531	$16,900	$20,081	$24,940	$31,743	$37,364	$37,809	$206,259

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[10] "Societal perspective" includes technology costs and societal costs, but does not include payment of civil penalties by manufacturers in lieu of compliance with the CAFE standards.

Table 6b
Incremental Total Costs by Societal Perspective, by Alternative
Light Trucks, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks										
Preferred Alternative	$487	$1,473	$2,998	$4,284	$6,200	$7,070	$7,909	$9,150	$10,720	$50,290
2% Annual Increase	$965	$1,707	$2,741	$3,385	$4,148	$4,510	$4,962	$5,466	$5,727	$33,612
3% Annual Increase	$1,527	$2,666	$3,950	$5,380	$6,897	$7,791	$8,407	$9,363	$10,512	$56,494
4% Annual Increase	$2,464	$4,022	$6,265	$8,680	$11,053	$12,318	$14,014	$15,053	$16,852	$90,720
5% Annual Increase	$3,510	$5,650	$8,366	$11,507	$14,798	$16,419	$18,008	$22,139	$23,318	$123,714
6% Annual Increase	$5,270	$7,906	$11,081	$14,955	$17,276	$19,048	$21,252	$24,302	$25,513	$146,602
7% Annual Increase	$6,298	$8,888	$11,960	$15,852	$17,533	$20,706	$23,318	$27,363	$26,529	$158,447
Max Net Benefits	$8,777	$9,847	$11,314	$13,683	$15,633	$16,360	$18,460	$21,140	$23,012	$138,225
Total Cost = Total Benefit	$8,738	$9,875	$11,324	$13,643	$15,766	$16,450	$19,110	$21,831	$23,616	$140,353

Table 6c
Incremental Total Costs by Societal Perspective, by Alternative
Combined, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars & Light Trucks					
Preferred Alternative	$2,571	$5,910	$10,386	$14,971	$19,845
2% Annual Increase	$1,868	$3,883	$6,372	$8,459	$10,418
3% Annual Increase	$3,028	$6,322	$9,894	$13,875	$17,538
4% Annual Increase	$5,332	$9,680	$14,987	$21,058	$26,242
5% Annual Increase	$8,275	$13,949	$20,012	$27,502	$36,284
6% Annual Increase	$11,990	$19,020	$25,969	$35,699	$41,919
7% Annual Increase	$14,076	$21,594	$28,590	$38,801	$43,647
Max Net Benefits	$17,019	$19,786	$25,151	$29,362	$32,741
Total Cost = Total Benefit	$18,923	$22,582	$25,855	$30,544	$35,847
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks					
Preferred Alternative	$22,998	$28,110	$33,479	$39,310	$177,579
2% Annual Increase	$11,891	$13,233	$15,238	$16,659	$88,020
3% Annual Increase	$20,199	$22,595	$25,962	$30,240	$149,653
4% Annual Increase	$29,657	$34,743	$41,235	$46,123	$229,057
5% Annual Increase	$40,683	$46,606	$62,576	$65,647	$321,534
6% Annual Increase	$47,679	$56,634	$78,608	$80,852	$398,370
7% Annual Increase	$52,084	$66,887	$87,269	$88,450	$441,397
Max Net Benefits	$34,076	$37,376	$41,373	$43,860	$280,743
Total Cost = Total Benefit	$41,390	$50,853	$59,195	$61,425	$346,613

Table 7a
Present Value of Lifetime Societal Benefits[11], by Alternative
Passenger Cars, (3% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$6,750	$12,833	$20,672	$28,358	$34,294
2% Annual Increase	$3,622	$7,262	$11,776	$16,236	$20,143
3% Annual Increase	$5,598	$11,552	$18,161	$24,751	$30,143
4% Annual Increase	$8,455	$15,431	$23,139	$31,481	$37,386
5% Annual Increase	$11,534	$19,215	$27,671	$36,976	$44,980
6% Annual Increase	$14,548	$22,794	$31,282	$41,881	$48,717
7% Annual Increase	$16,797	$25,535	$34,187	$44,924	$50,687
Max Net Benefits	$18,546	$21,999	$28,842	$33,951	$38,758
Total Cost = Total Benefit	$21,088	$25,817	$31,085	$36,734	$44,172
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$39,805	$47,859	$56,388	$66,112	$313,071
2% Annual Increase	$23,604	$26,497	$30,911	$34,501	$174,553
3% Annual Increase	$34,857	$39,406	$45,496	$52,720	$262,683
4% Annual Increase	$42,556	$48,624	$57,757	$66,009	$330,837
5% Annual Increase	$50,012	$57,048	$71,273	$80,929	$399,638
6% Annual Increase	$54,124	$62,710	$80,526	$92,493	$449,074
7% Annual Increase	$58,268	$70,271	$85,920	$98,104	$484,693
Max Net Benefits	$41,099	$44,553	$48,402	$52,662	$328,812
Total Cost = Total Benefit	$50,911	$60,049	$68,539	$76,016	$414,411

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[11] These benefits are considered from a "societal perspective" because they include externalities. They are distinguished from a consumer perspective, because consumers generally would not think about the value of carbon dioxide, energy security, etc.

Table 7b
Present Value of Lifetime Societal Benefits, by Alternative
Light Trucks, (3% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$2,137	$6,369	$13,480	$18,546	$26,283
2% Annual Increase	$4,051	$7,459	$12,945	$15,888	$20,031
3% Annual Increase	$6,022	$11,100	$17,537	$22,627	$28,308
4% Annual Increase	$8,732	$14,377	$22,226	$28,652	$35,476
5% Annual Increase	$10,894	$17,210	$25,370	$32,751	$41,140
6% Annual Increase	$13,815	$19,716	$28,961	$37,255	$43,344
7% Annual Increase	$15,023	$21,118	$30,523	$38,472	$43,510
Max Net Benefits	$19,388	$22,289	$28,681	$34,513	$41,336
Total Cost = Total Benefit	$19,456	$22,218	$28,575	$34,503	$41,455
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$29,699	$32,701	$37,346	$42,187	$208,747
2% Annual Increase	$21,938	$24,108	$26,288	$27,986	$160,694
3% Annual Increase	$31,730	$34,024	$37,551	$41,185	$230,084
4% Annual Increase	$39,695	$43,420	$46,721	$52,086	$291,385
5% Annual Increase	$45,536	$49,305	$55,738	$61,358	$339,302
6% Annual Increase	$47,477	$51,776	$57,416	$63,617	$363,378
7% Annual Increase	$49,951	$54,628	$61,530	$65,588	$380,343
Max Net Benefits	$44,002	$48,274	$53,343	$59,539	$351,366
Total Cost = Total Benefit	$44,073	$49,063	$54,118	$60,760	$354,221

Table 7c
Present Value of Lifetime Societal Benefits, by Alternative
Combined, (3% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars & Light Trucks					
Preferred Alternative	$8,887	$19,202	$34,152	$46,905	$60,577
2% Annual Increase	$7,674	$14,721	$24,721	$32,124	$40,175
3% Annual Increase	$11,621	$22,652	$35,698	$47,378	$58,450
4% Annual Increase	$17,188	$29,808	$45,365	$60,132	$72,862
5% Annual Increase	$22,429	$36,424	$53,041	$69,727	$86,120
6% Annual Increase	$28,363	$42,511	$60,243	$79,135	$92,061
7% Annual Increase	$31,821	$46,653	$64,710	$83,396	$94,197
Max Net Benefits	$37,934	$44,288	$57,523	$68,464	$80,094
Total Cost = Total Benefit	$40,543	$48,035	$59,661	$71,237	$85,627
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks					
Preferred Alternative	$69,504	$80,560	$93,734	$108,299	$521,818
2% Annual Increase	$45,542	$50,604	$57,199	$62,487	$335,246
3% Annual Increase	$66,587	$73,430	$83,047	$93,905	$492,767
4% Annual Increase	$82,251	$92,044	$104,478	$118,095	$622,223
5% Annual Increase	$95,548	$106,353	$127,011	$142,287	$738,940
6% Annual Increase	$101,601	$114,486	$137,942	$156,109	$812,452
7% Annual Increase	$108,219	$124,898	$147,451	$163,692	$865,036
Max Net Benefits	$85,101	$92,827	$101,746	$112,202	$680,178
Total Cost = Total Benefit	$94,984	$109,112	$122,656	$136,776	$768,632

Table 8a
Present Value of Net Total Benefits[12] by Alternative
Passenger Cars, (3% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars										
Preferred Alternative	$4,666	$8,396	$13,285	$17,671	$20,648	$23,877	$27,658	$32,059	$37,522	$185,782
2% Annual Increase	$2,719	$5,087	$8,145	$11,163	$13,874	$16,223	$18,226	$21,139	$23,570	$120,145
3% Annual Increase	$4,097	$7,896	$12,217	$16,255	$19,502	$22,450	$25,217	$28,897	$32,992	$169,524
4% Annual Increase	$5,587	$9,772	$14,417	$19,103	$22,197	$25,218	$27,896	$31,575	$36,737	$192,501
5% Annual Increase	$6,770	$10,915	$16,026	$20,981	$23,494	$25,748	$28,449	$30,836	$38,600	$201,819
6% Annual Increase	$7,828	$11,680	$16,394	$21,136	$24,074	$25,493	$27,328	$26,220	$37,154	$197,306
7% Annual Increase	$9,019	$12,829	$17,557	$21,975	$24,573	$26,890	$26,702	$26,014	$36,183	$201,743
Max Net Benefits	$10,304	$12,060	$15,005	$18,272	$21,650	$23,383	$25,636	$28,169	$31,815	$186,295
Total Cost = Total Benefit	$10,902	$13,110	$16,554	$19,833	$24,091	$25,971	$28,307	$31,175	$38,207	$208,151

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[12] This table is from a societal perspective, thus, civil penalties are deleted from the costs because they are a transfer payment (from manufacturers to the U.S. Treasury).

Table 8b
Present Value of Net Total Benefits by Alternative
Light Trucks, (3% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$1,650	$4,896	$10,482	$14,262	$20,084
2% Annual Increase	$3,087	$5,752	$10,204	$12,503	$15,883
3% Annual Increase	$4,495	$8,434	$13,587	$17,247	$21,411
4% Annual Increase	$6,269	$10,355	$15,961	$19,972	$24,424
5% Annual Increase	$7,384	$11,560	$17,004	$21,244	$26,342
6% Annual Increase	$8,545	$11,810	$17,880	$22,300	$26,068
7% Annual Increase	$8,725	$12,230	$18,563	$22,620	$25,977
Max Net Benefits	$10,611	$12,442	$17,367	$20,830	$25,703
Total Cost = Total Benefit	$10,718	$12,343	$17,252	$20,860	$25,688
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$22,629	$24,791	$28,196	$31,467	$158,457
2% Annual Increase	$17,428	$19,145	$20,822	$22,258	$127,082
3% Annual Increase	$23,939	$25,617	$28,188	$30,672	$173,590
4% Annual Increase	$27,376	$29,406	$31,668	$35,235	$200,665
5% Annual Increase	$29,117	$31,297	$33,599	$38,041	$215,587
6% Annual Increase	$28,430	$30,524	$33,114	$38,103	$216,776
7% Annual Increase	$29,245	$31,309	$34,167	$39,060	$221,896
Max Net Benefits	$27,642	$29,815	$32,204	$36,527	$213,141
Total Cost = Total Benefit	$27,623	$29,953	$32,286	$37,144	$213,868

Table 8c
Present Value of Net Total Benefits by Alternative
Combined, (3% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$6,316	$13,291	$23,766	$31,934	$40,732	$46,506	$52,450	$60,255	$68,989	$344,239
2% Annual Increase	$5,806	$10,838	$18,349	$23,666	$29,757	$33,651	$37,371	$41,961	$45,828	$247,227
3% Annual Increase	$8,592	$16,330	$25,803	$33,503	$40,913	$46,388	$50,835	$57,085	$63,665	$343,114
4% Annual Increase	$11,855	$20,128	$30,378	$39,075	$46,620	$52,594	$57,301	$63,243	$71,972	$393,166
5% Annual Increase	$14,154	$22,475	$33,030	$42,225	$49,836	$54,865	$59,746	$64,435	$76,640	$417,406
6% Annual Increase	$16,373	$23,491	$34,274	$43,436	$50,142	$53,922	$57,852	$59,334	$75,257	$414,082
7% Annual Increase	$17,744	$25,059	$36,120	$44,595	$50,550	$56,135	$58,012	$60,181	$75,242	$423,639
Max Net Benefits	$20,915	$24,502	$32,372	$39,103	$47,353	$51,025	$55,451	$60,373	$68,342	$399,436
Total Cost = Total Benefit	$21,620	$25,453	$33,806	$40,694	$49,780	$53,594	$58,259	$63,462	$75,351	$422,019

Table 9a
Incremental Total Costs by Societal Perspective[13], by Alternative
Passenger Cars, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$1,952	$4,190	$6,990	$10,151	$12,998
2% Annual Increase	$832	$2,033	$3,400	$4,760	$5,884
3% Annual Increase	$1,390	$3,431	$5,593	$8,024	$10,072
4% Annual Increase	$2,704	$5,365	$8,281	$11,786	$14,489
5% Annual Increase	$4,537	$7,932	$11,118	$15,300	$20,627
6% Annual Increase	$6,438	$10,673	$14,283	$19,946	$23,726
7% Annual Increase	$7,456	$12,220	$15,980	$22,103	$25,166
Max Net Benefits	$7,808	$9,439	$13,194	$14,978	$16,298
Total Cost = Total Benefit	$9,777	$12,214	$13,975	$16,168	$19,157
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$15,182	$19,320	$23,300	$27,379	$121,462
2% Annual Increase	$6,932	$7,769	$9,191	$10,283	$51,083
3% Annual Increase	$11,754	$13,454	$15,756	$18,751	$88,226
4% Annual Increase	$16,546	$19,831	$25,123	$28,054	$132,178
5% Annual Increase	$23,316	$27,525	$39,107	$40,819	$190,281
6% Annual Increase	$27,612	$34,198	$52,730	$53,485	$243,091
7% Annual Increase	$30,293	$42,227	$58,185	$59,894	$273,523
Max Net Benefits	$16,873	$17,824	$19,262	$19,898	$135,574
Total Cost = Total Benefit	$21,552	$28,551	$34,276	$35,020	$190,689

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[13] "Societal perspective" includes technology costs and societal costs, but does not include civil penalties.

Table 9b
Incremental Total Costs by Societal Perspective, by Alternative
Light Trucks, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$453	$1,373	$2,785	$3,996	$5,794
2% Annual Increase	$900	$1,589	$2,535	$3,135	$3,835
3% Annual Increase	$1,432	$2,492	$3,674	$5,028	$6,460
4% Annual Increase	$2,327	$3,797	$5,918	$8,240	$10,510
5% Annual Increase	$3,339	$5,381	$7,971	$11,005	$14,174
6% Annual Increase	$5,053	$7,582	$10,615	$14,373	$16,601
7% Annual Increase	$6,062	$8,542	$11,472	$15,248	$16,853
Max Net Benefits	$6,996	$7,931	$9,457	$10,754	$12,590
Total Cost = Total Benefit	$8,476	$9,542	$10,900	$13,125	$15,077
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$6,615	$7,411	$8,587	$10,086	$47,101
2% Annual Increase	$4,170	$4,591	$5,063	$5,301	$31,119
3% Annual Increase	$7,305	$7,889	$8,797	$9,892	$52,970
4% Annual Increase	$11,716	$13,357	$14,352	$16,076	$86,292
5% Annual Increase	$15,733	$17,269	$21,314	$22,414	$118,599
6% Annual Increase	$18,310	$20,457	$23,437	$24,572	$140,998
7% Annual Increase	$19,956	$22,500	$26,455	$25,565	$152,653
Max Net Benefits	$12,973	$13,703	$14,377	$14,024	$102,806
Total Cost = Total Benefit	$15,727	$18,372	$21,063	$22,752	$135,035

Table 9c
Incremental Total Costs by Societal Perspective, by Alternative
Combined, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$2,405	$5,564	$9,775	$14,147	$18,792	$21,797	$26,731	$31,886	$37,465	$168,563
2% Annual Increase	$1,731	$3,622	$5,935	$7,895	$9,719	$11,101	$12,360	$14,253	$15,584	$82,201
3% Annual Increase	$2,822	$5,923	$9,267	$13,053	$16,533	$19,060	$21,343	$24,552	$28,643	$141,196
4% Annual Increase	$5,031	$9,162	$14,199	$20,026	$24,999	$28,262	$33,188	$39,474	$44,130	$218,471
5% Annual Increase	$7,876	$13,313	$19,089	$26,305	$34,801	$39,049	$44,795	$60,420	$63,233	$308,881
6% Annual Increase	$11,491	$18,255	$24,898	$34,319	$40,327	$45,921	$54,654	$76,166	$78,057	$384,088
7% Annual Increase	$13,518	$20,762	$27,452	$37,351	$42,019	$50,249	$64,726	$84,640	$85,458	$426,176
Max Net Benefits	$14,804	$17,369	$22,651	$25,732	$28,888	$29,846	$31,527	$33,639	$33,923	$238,380
Total Cost = Total Benefit	$18,253	$21,756	$24,875	$29,294	$34,234	$37,279	$46,922	$55,340	$57,772	$325,725

Table 10a
Present Value of Lifetime Societal Benefits[14], by Alternative
Passenger Cars, (7% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$5,504	$10,466	$16,889	$23,167	$28,042
2% Annual Increase	$2,953	$5,923	$9,622	$13,265	$16,475
3% Annual Increase	$4,570	$9,429	$14,843	$20,227	$24,656
4% Annual Increase	$6,894	$12,580	$18,901	$25,714	$30,562
5% Annual Increase	$9,402	$15,660	$22,593	$30,195	$36,764
6% Annual Increase	$11,860	$18,576	$25,531	$34,194	$39,820
7% Annual Increase	$13,694	$20,822	$27,918	$36,693	$41,439
Max Net Benefits	$14,994	$17,744	$23,379	$27,656	$31,492
Total Cost = Total Benefit	$17,186	$21,046	$25,303	$29,954	$36,030
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$32,579	$39,157	$46,184	$54,199	$256,188
2% Annual Increase	$19,329	$21,712	$25,357	$28,327	$142,964
3% Annual Increase	$28,538	$32,287	$37,316	$43,271	$215,136
4% Annual Increase	$34,828	$39,799	$47,324	$54,135	$270,737
5% Annual Increase	$40,916	$46,723	$58,396	$66,356	$327,006
6% Annual Increase	$44,287	$51,320	$65,945	$75,812	$367,345
7% Annual Increase	$47,683	$57,520	$70,373	$80,417	$396,559
Max Net Benefits	$33,410	$35,960	$39,361	$42,961	$266,956
Total Cost = Total Benefit	$39,729	$47,479	$54,739	$60,797	$332,264

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[14] These benefits are considered from a "societal perspective" because they include externalities. They are distinguished from a consumer perspective, because consumers generally would not think about the value of carbon dioxide, energy security, etc.

Table 10b
Present Value of Lifetime Societal Benefits, by Alternative
Light Trucks, (7% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks										
Preferred Alternative	$1,714	$5,110	$10,792	$14,881	$21,096	$23,867	$26,298	$30,053	$33,963	$167,774
2% Annual Increase	$3,238	$5,971	$10,366	$12,741	$16,080	$17,637	$19,402	$21,156	$22,545	$129,137
3% Annual Increase	$4,815	$8,896	$14,042	$18,150	$22,711	$25,485	$27,351	$30,211	$33,151	$184,812
4% Annual Increase	$6,980	$11,515	$17,798	$22,990	$28,464	$31,881	$34,892	$37,579	$41,915	$234,013
5% Annual Increase	$8,709	$13,782	$20,310	$26,277	$33,041	$36,607	$39,649	$44,843	$49,381	$272,599
6% Annual Increase	$11,042	$15,767	$23,168	$29,874	$34,786	$38,138	$41,611	$46,181	$51,179	$291,746
7% Annual Increase	$12,007	$16,890	$24,408	$30,838	$34,884	$40,090	$43,864	$49,458	$52,742	$305,181
Max Net Benefits	$13,347	$15,816	$21,135	$24,755	$30,508	$32,429	$34,672	$36,381	$37,726	$246,768
Total Cost = Total Benefit	$15,633	$17,816	$22,922	$27,708	$33,146	$35,291	$39,397	$43,572	$48,941	$284,425

Table 10c
Present Value of Lifetime Societal Benefits, by Alternative Combined, (7% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars & Light Trucks					
Preferred Alternative	$7,218	$15,576	$27,682	$38,047	$49,138
2% Annual Increase	$6,192	$11,895	$19,988	$26,006	$32,555
3% Annual Increase	$9,384	$18,325	$28,885	$38,377	$47,367
4% Annual Increase	$13,874	$24,095	$36,699	$48,703	$59,027
5% Annual Increase	$18,110	$29,442	$42,904	$56,471	$69,806
6% Annual Increase	$22,902	$34,344	$48,698	$64,067	$74,606
7% Annual Increase	$25,701	$37,712	$52,326	$67,531	$76,323
Max Net Benefits	$28,342	$33,559	$44,513	$52,411	$62,000
Total Cost = Total Benefit	$32,820	$38,861	$48,224	$57,662	$69,176
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks					
Preferred Alternative	$56,447	$65,454	$76,237	$88,162	$423,961
2% Annual Increase	$36,965	$41,114	$46,513	$50,872	$272,101
3% Annual Increase	$54,023	$59,638	$67,527	$76,422	$399,948
4% Annual Increase	$66,709	$74,691	$84,903	$96,049	$504,750
5% Annual Increase	$77,523	$86,372	$103,239	$115,738	$599,605
6% Annual Increase	$82,425	$92,932	$112,126	$126,991	$659,091
7% Annual Increase	$87,773	$101,383	$119,831	$133,160	$701,740
Max Net Benefits	$65,839	$70,631	$75,742	$80,686	$513,724
Total Cost = Total Benefit	$75,020	$86,877	$98,311	$109,738	$616,689

Table 11a
Present Value of Net Total Benefits[15] by Alternative
Passenger Cars, (7% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars										
Preferred Alternative	$3,552	$6,276	$9,900	$13,015	$15,044	$17,397	$19,837	$22,884	$26,820	$134,726
2% Annual Increase	$2,122	$3,891	$6,222	$8,505	$10,591	$12,397	$13,943	$16,167	$18,044	$91,881
3% Annual Increase	$3,179	$5,999	$9,250	$12,202	$14,584	$16,784	$18,833	$21,560	$24,520	$126,910
4% Annual Increase	$4,190	$7,216	$10,621	$13,927	$16,073	$18,282	$19,968	$22,202	$26,080	$138,558
5% Annual Increase	$4,865	$7,728	$11,475	$14,895	$16,137	$17,601	$19,197	$19,290	$25,537	$136,725
6% Annual Increase	$5,422	$7,903	$11,247	$14,248	$16,094	$16,675	$17,122	$13,215	$22,327	$124,255
7% Annual Increase	$6,238	$8,602	$11,937	$14,590	$16,274	$17,389	$15,293	$12,189	$20,524	$123,037
Max Net Benefits	$7,187	$8,305	$10,184	$12,678	$15,194	$16,537	$18,136	$20,099	$23,062	$131,382
Total Cost = Total Benefit	$7,410	$8,832	$11,328	$13,786	$16,873	$18,177	$18,928	$20,463	$25,777	$141,574

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[15] This table is from a societal perspective, thus, civil penalties are deleted from the costs because they are a transfer payment.

Table 11b
Present Value of Net Total Benefits by Alternative
Light Trucks, (7% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$1,261	$3,737	$8,007	$10,885	$15,302
2% Annual Increase	$2,339	$4,382	$7,831	$9,606	$12,245
3% Annual Increase	$3,383	$6,403	$10,368	$13,122	$16,251
4% Annual Increase	$4,654	$7,718	$11,880	$14,750	$17,954
5% Annual Increase	$5,370	$8,401	$12,340	$15,272	$18,868
6% Annual Increase	$5,990	$8,185	$12,553	$15,501	$18,185
7% Annual Increase	$5,945	$8,348	$12,936	$15,590	$18,031
Max Net Benefits	$6,351	$7,885	$11,678	$14,001	$17,918
Total Cost = Total Benefit	$7,157	$8,273	$12,022	$14,582	$18,069
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$17,252	$18,886	$21,466	$23,877	$120,673
2% Annual Increase	$13,467	$14,811	$16,093	$17,244	$98,019
3% Annual Increase	$18,180	$19,462	$21,415	$23,259	$131,842
4% Annual Increase	$20,165	$21,535	$23,227	$25,839	$147,721
5% Annual Increase	$20,874	$22,380	$23,529	$26,967	$154,000
6% Annual Increase	$19,828	$21,155	$22,745	$26,607	$150,748
7% Annual Increase	$20,134	$21,364	$23,003	$27,178	$152,528
Max Net Benefits	$19,456	$20,969	$22,003	$23,701	$143,962
Total Cost = Total Benefit	$19,563	$21,026	$22,509	$26,189	$149,390

Table 11c
Present Value of Net Total Benefits by Alternative
Combined, (7% Discount Rate)
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$4,813	$10,013	$17,907	$23,900	$30,346	$34,649	$38,724	$44,351	$50,697	$255,399
2% Annual Increase	$4,460	$8,273	$14,053	$18,111	$22,836	$25,864	$28,754	$32,260	$35,288	$189,900
3% Annual Increase	$6,562	$12,402	$19,617	$25,324	$30,835	$34,964	$38,295	$42,975	$47,778	$258,751
4% Annual Increase	$8,843	$14,934	$22,501	$28,677	$34,027	$38,447	$41,503	$45,429	$51,919	$286,279
5% Annual Increase	$10,234	$16,129	$23,815	$30,166	$35,005	$38,474	$41,578	$42,819	$52,504	$290,725
6% Annual Increase	$11,412	$16,088	$23,800	$29,749	$34,279	$36,503	$38,277	$35,960	$48,934	$275,003
7% Annual Increase	$12,183	$16,950	$24,873	$30,180	$34,305	$37,524	$36,657	$35,191	$47,702	$275,565
Max Net Benefits	$13,538	$16,190	$21,862	$26,678	$33,112	$35,993	$39,104	$42,102	$46,763	$275,344
Total Cost = Total Benefit	$14,567	$17,105	$23,349	$28,368	$34,942	$37,740	$39,954	$42,972	$51,966	$290,964

Table 12a
Millions of Gallons of Fuel Saved[16]
Passenger Cars
Undiscounted Over the Lifetime of the Model Year

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	2,120	3,995	6,368	8,639	10,484
2% Annual Increase	1,140	2,266	3,636	4,964	6,091
3% Annual Increase	1,757	3,581	5,558	7,516	9,063
4% Annual Increase	2,654	4,779	7,091	9,577	11,373
5% Annual Increase	3,716	6,078	8,600	11,389	13,971
6% Annual Increase	4,652	7,262	9,845	13,094	15,061
7% Annual Increase	5,246	8,029	10,655	13,940	15,579
Max Net Benefits (3% Discount Rate)	5,820	6,941	8,999	10,469	11,814
Max Net Benefits (7% Discount Rate)	5,773	6,868	8,933	10,438	11,744
Total Cost = Total Benefit (3% Discount Rate)	6,717	8,142	9,675	11,384	13,556
Total Cost = Total Benefit (7% Discount Rate)	6,716	8,142	9,678	11,362	13,519
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	12,056	14,414	16,809	19,690	94,575
2% Annual Increase	7,077	7,878	9,110	10,125	52,288
3% Annual Increase	10,423	11,681	13,374	15,536	78,489
4% Annual Increase	12,829	14,603	17,266	19,679	99,851
5% Annual Increase	15,438	17,431	21,605	24,369	122,597
6% Annual Increase	16,591	19,112	24,243	27,619	137,479
7% Annual Increase	17,753	21,254	25,655	29,078	147,189
Max Net Benefits (3% Discount Rate)	12,423	13,343	14,360	15,553	99,722
Max Net Benefits (7% Discount Rate)	12,344	13,162	14,262	15,483	99,007
Total Cost = Total Benefit (3% Discount Rate)	15,492	18,156	20,546	22,717	126,385
Total Cost = Total Benefit (7% Discount Rate)	14,745	17,518	19,996	22,123	123,799

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[16] The choice of a 3 or 7 percent discount rate can impact the results of the Max Net Benefits and Total Cost = Total Benefits scenarios. The results of all other scenarios are not impacted by choice of discount rate. Results for both 3 and 7 percent discount rates are therefore presented for both Max Net Benefits and Total Cost = Total Benefit scenarios.

Table 12b
Millions of Gallons of Fuel Saved
Light Trucks
Undiscounted Over the Lifetime of the Model Year

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	685	2,026	4,297	5,817	8,183
2% Annual Increase	1,315	2,399	4,133	5,028	6,275
3% Annual Increase	1,950	3,542	5,579	7,134	8,849
4% Annual Increase	2,826	4,640	7,119	9,019	11,089
5% Annual Increase	3,526	5,580	8,172	10,389	13,000
6% Annual Increase	4,478	6,559	9,466	11,955	13,935
7% Annual Increase	4,883	7,011	9,955	12,382	13,886
Max Net Benefits (3% Discount Rate)	6,293	7,322	9,312	11,063	13,088
Max Net Benefits (7% Discount Rate)	5,406	6,490	8,614	9,916	12,059
Total Cost = Total Benefit (3% Discount Rate)	6,294	7,325	9,305	11,076	13,148
Total Cost = Total Benefit (7% Discount Rate)	6,326	7,342	9,331	11,098	13,114
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	9,149	9,991	11,310	12,754	64,212
2% Annual Increase	6,792	7,388	8,013	8,458	49,802
3% Annual Increase	9,813	10,431	11,408	12,519	71,224
4% Annual Increase	12,283	13,425	14,314	15,848	90,564
5% Annual Increase	14,231	15,289	17,190	18,787	106,162
6% Annual Increase	15,139	16,351	17,907	19,709	115,499
7% Annual Increase	15,733	17,048	18,948	20,079	119,925
Max Net Benefits (3% Discount Rate)	13,776	14,995	16,387	18,177	110,413
Max Net Benefits (7% Discount Rate)	12,675	13,430	13,957	14,335	96,881
Total Cost = Total Benefit (3% Discount Rate)	13,824	15,254	16,708	18,597	111,531
Total Cost = Total Benefit (7% Discount Rate)	13,792	15,249	16,727	18,616	111,593

Table 12c
Millions of Gallons of Fuel Saved
Combined
Undiscounted Over the Lifetime of the Model Year

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	2,805	6,022	10,665	14,456	18,667	21,205	24,405	28,119	32,444	158,787
2% Annual Increase	2,456	4,665	7,769	9,992	12,366	13,870	15,267	17,124	18,583	102,090
3% Annual Increase	3,707	7,123	11,138	14,649	17,912	20,235	22,112	24,781	28,055	149,713
4% Annual Increase	5,480	9,419	14,210	18,597	22,462	25,112	28,028	31,579	35,528	190,415
5% Annual Increase	7,242	11,657	16,772	21,778	26,971	29,669	32,720	38,795	43,157	228,759
6% Annual Increase	9,131	13,821	19,311	25,049	28,996	31,730	35,463	42,150	47,327	252,978
7% Annual Increase	10,129	15,040	20,610	26,322	29,465	33,487	38,302	44,603	49,157	267,115
Max Net Benefits (3% Discount Rate)	12,113	14,263	18,311	21,532	24,902	26,199	28,337	30,747	33,730	210,134
Max Net Benefits (7% Discount Rate)	11,179	13,358	17,548	20,354	23,803	25,019	26,591	28,219	29,818	195,889
Total Cost = Total Benefit (3% Discount Rate)	13,011	15,467	18,980	22,460	26,704	29,316	33,410	37,254	41,314	237,916
Total Cost = Total Benefit (7% Discount Rate)	13,042	15,483	19,009	22,459	26,633	28,537	32,767	36,722	40,739	235,392

Table 12d
Change in Electricity Consumption (in GW-h)
Passenger Cars
Undiscounted Over the Lifetime of the Model Year

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	-6.8	-7.0	16.9	185.5	479.4
2% Annual Increase	-6.8	-7.0	-7.2	-7.0	-7.2
3% Annual Increase	-6.8	-7.0	-7.2	16.6	17.0
4% Annual Increase	-6.8	-7.0	-7.2	424.8	965.3
5% Annual Increase	10.3	813.9	939.0	1,654.7	4,774.4
6% Annual Increase	10.3	813.9	1,135.4	5,980.6	8,528.9
7% Annual Increase	576.6	2,132.6	2,568.3	10,326.0	11,883.1
Max Net Benefits (3% Discount Rate)	910.3	922.6	4,160.3	4,693.2	5,106.8
Max Net Benefits (7% Discount Rate)	910.3	922.6	4,160.3	4,693.2	5,106.8
Total Cost = Total Benefit (3% Discount Rate)	910.3	1,822.3	1,834.9	1,892.8	2,652.2
Total Cost = Total Benefit (7% Discount Rate)	910.3	1,822.3	1,834.9	1,892.8	2,546.2
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	494.8	5,165.9	5,850.6	16,280.9	28,460.3
2% Annual Increase	-7.2	63.4	214.0	1,659.0	1,893.9
3% Annual Increase	18.2	89.6	309.1	4,580.3	5,009.8
4% Annual Increase	969.8	4,872.7	7,197.9	16,420.3	30,829.9
5% Annual Increase	6,870.7	12,033.9	24,720.4	35,241.4	87,058.6
6% Annual Increase	12,199.0	20,434.3	41,327.6	57,076.2	147,506.1
7% Annual Increase	19,360.3	35,126.2	53,854.8	68,386.4	204,214.3
Max Net Benefits (3% Discount Rate)	5,343.6	5,817.0	6,393.3	10,013.7	43,360.8
Max Net Benefits (7% Discount Rate)	5,343.6	5,817.0	6,393.3	9,537.0	42,884.1
Total Cost = Total Benefit (3% Discount Rate)	8,075.0	17,796.8	22,179.7	30,782.1	87,946.1
Total Cost = Total Benefit (7% Discount Rate)	3,684.4	13,414.6	17,800.8	26,103.5	70,009.8

Table 12e
Change in Electricity Consumption (in GW-h)
Light Trucks
Undiscounted Over the Lifetime of the Model Year

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	0	0	0	0	0
2% Annual Increase	0	0	0	0	0
3% Annual Increase	0	0	0	0	0
4% Annual Increase	0	0	0	0	0
5% Annual Increase	0	0	0	1.7	1.6
6% Annual Increase	0	733.8	708.6	727.2	724.6
7% Annual Increase	0	733.8	708.6	727.2	724.6
Max Net Benefits (3% Discount Rate)	0	771.9	746.2	736.9	734.2
Max Net Benefits (7% Discount Rate)	0	0.0	0.0	1.7	1.6
Total Cost = Total Benefit (3% Discount Rate)	0	776.8	751.1	736.9	734.3
Total Cost = Total Benefit (7% Discount Rate)	0	776.8	751.1	736.9	734.3
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	0	0	0	0	0
2% Annual Increase	0	0	0	0	0
3% Annual Increase	0	0	0	0	0
4% Annual Increase	0	0	0	280.3	280.3
5% Annual Increase	457.5	2,041.7	4,683.9	4,709.1	11,895.5
6% Annual Increase	1,187.7	3,355.7	5,051.0	8,088.8	20,577.5
7% Annual Increase	5,011.4	6,448.3	8,993.5	9,199.0	32,546.4
Max Net Benefits (3% Discount Rate)	741.5	2,211.3	2,267.1	2,271.7	10,480.8
Max Net Benefits (7% Discount Rate)	1.6	1.5	1.7	1.7	9.8
Total Cost = Total Benefit (3% Discount Rate)	741.5	2,211.3	3,815.6	4,447.5	14,215.1
Total Cost = Total Benefit (7% Discount Rate)	741.5	2,211.3	3,815.6	4,447.5	14,215.1

Table 12f
Change in Electricity Consumption (in GW-h)
Combined
Undiscounted Over the Lifetime of the Model Year

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars & Light Trucks					
Preferred Alternative	-6.8	-7.0	16.9	185.5	479.4
2% Annual Increase	-6.8	-7.0	-7.2	-7.0	-7.2
3% Annual Increase	-6.8	-7.0	-7.2	16.6	17.0
4% Annual Increase	-6.8	-7.0	-7.2	424.8	965.3
5% Annual Increase	10.3	813.9	939.0	1,656.4	4,775.9
6% Annual Increase	10.3	1,547.7	1,844.0	6,707.7	9,253.5
7% Annual Increase	576.6	2,866.4	3,276.9	11,053.2	12,607.7
Max Net Benefits (3% Discount Rate)	910.3	1,694.5	4,906.6	5,430.1	5,841.1
Max Net Benefits (7% Discount Rate)	910.3	922.6	4,160.3	4,694.9	5,108.5
Total Cost = Total Benefit (3% Discount Rate)	910.3	2,599.1	2,586.0	2,629.7	3,386.5
Total Cost = Total Benefit (7% Discount Rate)	910.3	2,599.1	2,586.0	2,629.7	3,280.5
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks					
Preferred Alternative	494.8	5,165.9	5,850.6	16,280.9	28,460.3
2% Annual Increase	-7.2	63.4	214.0	1,659.0	1,893.9
3% Annual Increase	18.2	89.6	309.1	4,580.3	5,009.8
4% Annual Increase	969.8	4,872.7	7,197.9	16,700.6	31,110.1
5% Annual Increase	7,328.2	14,075.6	29,404.3	39,950.5	98,954.1
6% Annual Increase	13,386.7	23,790.1	46,378.6	65,165.0	168,083.5
7% Annual Increase	24,371.7	41,574.5	62,848.3	77,585.4	236,760.7
Max Net Benefits (3% Discount Rate)	6,085.1	8,028.3	8,660.4	12,285.4	53,841.6
Max Net Benefits (7% Discount Rate)	5,345.2	5,818.5	6,394.9	9,538.7	42,893.9
Total Cost = Total Benefit (3% Discount Rate)	8,816.5	20,008.1	25,995.3	35,229.6	102,161.2
Total Cost = Total Benefit (7% Discount Rate)	4,426.0	15,625.9	21,616.4	30,551.0	84,224.9

Breakdown of Costs and Benefits for the Preferred Alternative

Tables 13 and 14 provide a breakdown of the costs and benefits for the preferred alternative using a 3 percent and 7 percent discount rate, respectively.

Table 13
Preferred Alternative
Cost and Benefit Estimates, 3% Discount Rate
Passenger Cars and Light Trucks Combined
(Millions of 2009 Dollars)

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Technology Costs	($1,738)	($4,180)	($7,289)	($10,826)	($14,559)
Social Costs and Benefits					
Lifetime Fuel Expenditures (Pretax)	$7,079	$15,305	$27,328	$37,377	$48,448
Consumer Surplus from Additional Driving	$57	$184	$416	$625	$869
Refueling Time Value	$365	$700	$1,161	$1,620	$1,833
Petroleum Market Externalities	$380	$813	$1,440	$1,952	$2,521
Congestion Costs	($554)	($1,149)	($2,020)	($2,725)	($3,480)
Accident Costs	($255)	($539)	($954)	($1,292)	($1,660)
Noise Costs	($10)	($22)	($38)	($52)	($66)
Fatality Costs	$18	$59	($85)	$14	($9)
CO2	$738	$1,608	$2,900	$4,015	$5,228
CO	$0	$0	$0	$0	$0
VOC	$8	$19	$34	$46	$68
NOX	$17	$31	$51	$71	$56
PM	$106	$231	$415	$558	$776
SOX	$108	$231	$408	$549	$706
Net Social Benefits	$8,054	$17,471	$31,055	$42,759	$55,291
Net Total Benefits	$6,316	$13,291	$23,766	$31,934	$40,732

Table 13 (Continued)

	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Technology Costs	($16,974)	($21,168)	($25,479)	($29,924)	($132,137)
Social Costs and Benefits					
Lifetime Fuel Expenditures (Pretax)	$55,504	$64,285	$74,647	$86,483	$416,456
Consumer Surplus from Additional Driving	$1,063	$1,448	$1,868	$2,575	$9,105
Refueling Time Value	$2,081	$2,290	$2,658	$2,585	$15,292
Petroleum Market Externalities	$2,865	$3,310	$3,817	$4,449	$21,547
Congestion Costs	($3,987)	($4,594)	($5,331)	($6,199)	($30,040)
Accident Costs	($1,899)	($2,187)	($2,533)	($2,931)	($14,250)
Noise Costs	($76)	($87)	($101)	($117)	($568)
Fatality Costs	$41	$9	$9	($47)	$10
CO2	$6,057	$7,081	$8,321	$9,667	$45,614
CO	$0	$0	$0	$0	$0
VOC	$78	$95	$110	$141	$601
NOX	$59	$94	$107	$109	$594
PM	$889	$1,063	$1,224	$1,444	$6,705
SOX	$804	$811	$938	$844	$5,401
Net Social Benefits	$63,479	$73,618	$85,734	$99,004	$476,467
Net Total Benefits	$46,506	$52,450	$60,255	$69,080	$344,330

Table 14
Preferred Alternative
Cost and Benefit Estimates, 7% Discount Rate
Passenger Cars and Light Trucks Combined
(Millions of 2009 Dollars)

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Technology Costs	($1,738)	($4,180)	($7,289)	($10,826)	($14,559)
Social Costs and Benefits					
Lifetime Fuel Expenditures (Pretax)	$5,614	$12,118	$21,639	$29,600	$38,376
Consumer Surplus from Additional Driving	$45	$146	$329	$496	$689
Refueling Time Value	$292	$560	$928	$1,295	$1,463
Petroleum Market Externalities	$304	$650	$1,149	$1,558	$2,012
Congestion Costs	($442)	($917)	($1,611)	($2,174)	($2,777)
Accident Costs	($204)	($429)	($760)	($1,030)	($1,323)
Noise Costs	($8)	($17)	($30)	($41)	($53)
Fatality Costs	$18	$59	($85)	$14	($9)
CO2	$738	$1,608	$2,900	$4,015	$5,228
CO	$0	$0	$0	$0	$0
VOC	$7	$15	$28	$38	$55
NOX	$14	$27	$44	$61	$50
PM	$87	$189	$339	$456	$630
SOX	$86	$184	$326	$438	$564
Net Social Benefits	$6,551	$14,193	$25,196	$34,726	$44,905
Net Total Benefits	$4,813	$10,013	$17,907	$23,900	$30,346

Table 14 (Continued)

	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Technology Costs	($16,974)	($21,168)	($25,479)	($29,924)	($132,137)
Social Costs and Benefits					
Lifetime Fuel Expenditures (Pretax)	$44,014	$51,011	$59,299	$68,789	$330,460
Consumer Surplus from Additional Driving	$844	$1,150	$1,487	$2,056	$7,242
Refueling Time Value	$1,661	$1,829	$2,124	$2,065	$12,217
Petroleum Market Externalities	$2,287	$2,643	$3,050	$3,558	$17,211
Congestion Costs	($3,186)	($3,673)	($4,267)	($4,968)	($24,015)
Accident Costs	($1,515)	($1,746)	($2,024)	($2,346)	($11,376)
Noise Costs	($60)	($70)	($81)	($94)	($454)
Fatality Costs	$41	$9	$9	($47)	$10
CO2	$6,057	$7,081	$8,321	$9,667	$45,614
CO	$0	$0	$0	$0	$0
VOC	$63	$76	$88	$113	$483
NOX	$54	$80	$91	$93	$513
PM	$721	$852	$983	$1,148	$5,405
SOX	$642	$649	$750	$673	$4,313
Net Social Benefits	$51,623	$59,892	$69,829	$80,708	$387,623
Net Total Benefits	$34,649	$38,724	$44,351	$50,784	$255,486

Annualized Costs and Benefits for the Preferred Alternative

Tables 15 and 16 present the annualized costs and benefits of the MY 2017-2025 CAFE rule, at 3 and 7 percent discount rates respectively. "Annualization" is a generic term used to refer to the estimation of the annual payment that would be required to pay back a loan at a given rate on a constant payment schedule for a set duration. In the context of NHTSA's analysis of the impact of the proposed CAFE rule, annualized costs can be interpreted as society's yearly "mortgage payment" on both the technology and social costs of this rule. Similarly, annualized benefits represent the average value of the stream of benefits per year that society receives as a result of this rule over the duration of the given fleet's life.[17]

In Tables 15 and 16, each model year's costs and benefits are annualized to a base year of 2017. Annualized net benefits are the difference between annualized costs and annualized benefits. While it may seem counterintuitive that total annualized net benefits are greater in the case of a 7 percent discount rate versus a 3 percent discount rate, this outcome is a consequence of the concept of annualization in that the use of the higher rate results in higher societal costs, as the "principal" is paid back at a higher interest rate, while benefits are also greater, as the benefit "payments" to society are also made at a higher interest rate.

Table 15
Annualized Costs, Benefits, and Net Benefits by Model Year
Passenger Cars and Light Trucks Combined
(Billions of 2009$, 3% Discount Rate)

	Annualized		
Model Year	**Costs**	**Benefits**	**Net Benefits**
MY 2017	($0.1)	$0.7	$0.6
MY 2018	($0.3)	$1.5	$1.2
MY 2019	($0.5)	$2.6	$2.1
MY 2020	($0.6)	$3.4	$2.8
MY 2021	($0.8)	$4.3	$3.4
MY 2022	($0.9)	$4.8	$3.8
MY 2023	($1.1)	$5.3	$4.2
MY 2024	($1.2)	$6.0	$4.8
MY 2025	($1.4)	$6.8	$5.4
Total	($7.0)	$35.3	$28.4

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[17] In the calculation of annualized costs and benefits, a 36-year lifetime was applied to the combined fleet for each model year.

Table 16
Annualized Costs, Benefits, and Net Benefits by Model Year
Passenger Cars and Light Trucks Combined
(Billions of 2009$, 7% Discount Rate)

	Annualized		
Model Year	**Costs**	**Benefits**	**Net Benefits**
MY 2017	($0.2)	$0.9	$0.7
MY 2018	($0.4)	$1.8	$1.4
MY 2019	($0.7)	$3.1	$2.4
MY 2020	($0.9)	$3.9	$3.1
MY 2021	($1.1)	$4.8	$3.7
MY 2022	($1.2)	$5.1	$3.9
MY 2023	($1.4)	$5.5	$4.2
MY 2024	($1.5)	$6.0	$4.5
MY 2025	($1.6)	$6.5	$4.9
Total	($8.9)	$37.8	$28.9

I. INTRODUCTION

The purpose of this study is to analyze the effects of the proposal that would extend the National Program of Federal and corporate average fuel economy (CAFE) standards and greenhouse gas (GHG) emissions standards to model years (MYs) 2017-2025 for passenger cars and light trucks. Under this joint rulemaking, NHTSA is proposing CAFE standards under Energy Policy Conservation Act of 1975, as amended by the Energy Independence and Security Act of 2007 (EISA), and EPA is proposing GHG emissions standards under the Clean Air Act (CAA). This study includes a discussion of the technologies that can improve fuel economy, the potential impacts on retail prices, safety, the discounted lifetime net benefits of fuel savings, and the potential gallons of fuel saved, among other things.

In working together to develop the next round of standards for MYs 2017-2025, NHTSA and EPA are building on the success of the first phase of the National Program to regulate fuel economy and GHG emissions from U.S. light-duty vehicles, which established the coordinated standards for model years (MY) 2012-2016.[18] Continuing the National Program would ensure that all manufacturers can build a single fleet of U.S. vehicles that would satisfy all requirements under both programs as well as under California's program, helping to reduce costs and regulatory complexity while providing significant energy security and environmental benefits. President Obama announced plans for these proposed rules on July 29, 2011 and NHTSA and EPA issued a Supplemental Notice of Intent (NOI) outlining the agencies' plans for proposing the MY 2017-2025 standards and program.[19] The State of California and thirteen auto manufacturers representing over 90 percent of U.S. vehicle sales provided letters of support for the program concurrent with the Supplemental NOI.[20] The United Auto Workers (UAW) also supported the announcement.[21] As envisioned in the Presidential announcement and Supplemental NOI, the proposal sets forth proposed MYs 2017-2025 standards as well as detailed supporting analysis for those standards and regulatory alternatives for public review and comment.

One aspect of this phase of the National Program that is unique for NHTSA, however, is that the passenger car and light truck CAFE standards for MYs 2022-2025 must be conditional, while EPA's (and also California's) standards for those model years will be legally binding when adopted in this round. EISA requires NHTSA to issue CAFE standards for "at least 1, but not more than 5, model years."[22] To maintain the harmonization benefits of the National Program, NHTSA will therefore propose and adopt standards for all 9 model years from 2017-2025, but the last 4 years of standards will be conditional. The passenger car and light truck CAFE standards for MYs 2022-2025 will be determined with finality in a subsequent, *de novo* notice and comment

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[18] Final Rule published in the Federal Register on May 7, 2010 (75FR 25324).

[19] 76 FR 48758 (August 9, 2011).

[20] Commitment letters are available at http://www.nhtsa.gov/fuel-economy (last accessed Aug. 24, 2011).

[21] The UAW's support was expressed in a statement on July 29, 2011, which can be found at http://www.uaw.org/articles/uaw-supports-administration-proposal-light-duty-vehicle-cafe-and-greenhouse-gas-emissions-r (last accessed September 19, 2011)

[22] 49 U.S.C. 32902(b)(3)(B).

rulemaking conducted in full compliance with EPCA/EISA and other applicable law – beyond simply reviewing the analysis and findings in the present rulemaking to see whether they are still accurate and applicable, and taking a fresh look at all relevant factors based on the best and most current information available at that future time.

To facilitate that future rulemaking, NHTSA and EPA will conduct a comprehensive mid-term evaluation. Up to date information will be developed and compiled for the evaluation, through a collaborative, robust, and transparent process, including notice and comment. The agencies fully expect to conduct the mid-term evaluation in close coordination with the California Air Resources Board (CARB), consistent with the agencies' commitment to maintaining a single national framework for regulation of fuel economy and GHG emissions.[23]

NHTSA examined regulatory alternatives in two ways. First, we examined these alternatives considering how maximum feasible standards can be set within the limitations of EPCA/EISA. In conducting this "estimated required" or "standard setting" analysis, NHTSA assumes manufacturers *do not* use dedicated alternative fuel vehicles, electric vehicles, plug-in electric vehicles, dual-fueled alternative fuel vehicles (through MY 2020), or credits earned for over-compliance to meet the required mpg levels, as directed by 49 U.S.C. 32902(h).

Second, we conducted more of a real-world analysis of what manufacturers are likely to do under CAFE standards and taking advantage of flexibilities and adjustments offered under CAFE standards, as actually provided by EPCA/EISA. In conducting this "projected achieved" or "real world under EPCA/EISA" analysis, NHTSA assumes manufacturers *will* use dedicated alternative fuel vehicles, electric vehicles, plug-in electric vehicles, dual-fueled alternative fuel vehicles (for all model years), and flexibilities allowed in the proposal and credits earned for over-compliance to meet the required mpg levels.

Under both types of analysis, NHTSA assumes some manufacturers will continue, as they have done historically, not to meet the standards and instead pay civil penalties for non-compliance, as permitted by EPCA. NHTSA also assumes manufacturers will apply A/C efficiency improvements and off-cycle technology improvements to meet the standards.

The analysis contained in this document reflects the impacts that NHTSA believes would result from manufacturers increasing the fuel economy of their vehicles in order to meet the stringency levels required or projected to be achieved under the different regulatory alternatives. When the agency was examining issues that relate to standard setting and the "estimated required" mpg levels, then the analysis is based on the "estimated required" mpg levels. Thus, analyses in Chapter V on technology relate to the amount of technology needed to get to the "estimated required" mpg level. Analyses in Chapter X relating to Sensitivity Analyses and Chapter XI on probabilistic uncertainties relate to the "estimated required" mpg level. However, estimates of the levels to be achieved by

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[23] The agencies also fully expect that any adjustments to the standards as a result of the mid-term evaluation process from the levels enumerated in the current rulemaking will be made with the participation of CARB and in a manner that continues the harmonization of state and Federal vehicle standards.

manufacturers (Chapter VI), costs and sales (Chapter VII), benefits and fuel savings (Chapter VIII), impact of weight reduction on safety (Chapter IX),and net benefits (Chapter X) are based on the more real world “projected achieved” mpg levels that are more likely to be achieved by the manufacturers.

II. NEED OF THE NATION TO CONSERVE ENERGY

The Energy Policy and Conservation Act (EPCA) states that:

> "When deciding maximum feasible average fuel economy … the Secretary of Transportation shall consider technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy."[24]

Thus, EPCA specifically directs the Department to balance the technological and economic challenges related to fuel economy with the Nation's need to conserve energy. The concerns about energy security and the effects of energy prices and supply on National economic well-being that led to the enactment of EPCA persist today. The demand for petroleum grew in the U.S. up through the year 2005, peaking at 20.8 million barrels per day, and has since declined to an average of 18.8 million barrels per day in 2009.[25] World demand, however, is expected to continue to rise until 2035.[26]

Since 1970, there have been a series of events that suggest that the behavior of petroleum markets is a matter for public concern.

- Average annual crude oil prices rose from $68 per barrel in 2007 to $95 per barrel in 2008, having peaked at $129 per barrel in July 2008. Prices declined to $37 per barrel in January 2009, but then rose to $113 per barrel in April 2011.[27] As recently as 1998, crude prices averaged about $13 per barrel.[28] Gasoline prices more than tripled during this ten-year period, from an annual average of $1.07 in 1998 to $3.30 in 2008. As the price of oil bounces up and down, the price of gasoline also rises and falls, hitting an average of $3.71 in July of 2011.[29]

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[24] 49 U.S.C. § 32902(f)

[25] U.S. Department of Energy, Energy Information Administration, *International Energy Statistics*, Total Petroleum Consumption. *See* http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=5&pid=5&aid=2 (last accessed, August 30, 2011).

[26] U.S Department of Energy, Energy Information Administration, *International Energy Outlook 2010*. *See* http://www.eia.gov/oiaf/ieo/highlights.html (last accessed August 30, 2011).

[27] U.S. Department of Energy, Energy Information Administration, *Short-Term Energy Outlook*, U.S. Refiner Average Acquisition Cost per Barrel of Crude Oil. *See* http://www.eia.gov/emeu/steo/pub/cf_query/index.cfm (last accessed August 30, 2011).

[28] Ibid.

[29] U.S. Department of Energy, Energy Information Administration, *Weekly Retail and Gasoline Diesel Prices*. *See* http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_m.htm (last accessed, August 30, 2011).

- U.S. domestic petroleum production stood at 10 million barrels per day in 1975, rose slightly to 10.6 million barrels per day in 1985, and by 2009 had declined to 7.3 million barrels per day.[30] Domestic production is predicted to increase through 2035. Between 1975 and 2005, U.S. petroleum consumption increased from 16.3 million barrels per day to 20.8 million barrels per day.[31] In 2009, vehicle miles traveled and consumption fell compared to the 2005 levels. Net petroleum imports accounted for 51.5 percent of U.S. domestic petroleum consumption in 2009.[32] Worldwide oil demand is fairly inelastic: declining prices do not induce large increases in consumption, while higher prices do not significantly restrain consumption. For example, the price of unleaded regular gasoline rose from an average of $2.57 in 2006 to $3.25 in 2008 (a 26.5 percent increase)[33] and vehicle miles traveled decreased by 1.3 percent.[34] Within the United States, demand for gasoline, diesel, and jet fuel within the transportation sector is particularly inelastic.
- Demand for oil is projected to increase significantly worldwide in the next several decades, resulting in upward oil cost pressure. Between 2007 and 2035, total world petroleum consumption is expected to grow from 86.1 to 110.6 million barrels per day.[35]
- Foreign oil production facilities, refineries, and supply chains have been disrupted from time to time, either by wars, political action by oil producers, civil unrest, or natural disasters.
- High oil prices, sometimes induced by disruptions in oil markets, have often coincided with rising inflation and subsequent economic recessions.
- Greenhouse gas emissions from the consumption of petroleum have become a subject of increasing public policy concern, both in the United States and internationally. Greenhouse gases in general and carbon dioxide in particular have not thus far been subject to National regulation. Studies by multiple sources suggest that rising atmospheric concentrations of greenhouse gases will damage human health and welfare.[36] There is a direct linkage between the consumption of fossil energy and emissions of the greenhouse gas carbon dioxide, as essentially all of the carbon in hydrocarbon fuels is oxidized into carbon dioxide when the fuel is combusted. Reducing U.S. fossil petroleum consumption will generally induce a proportional reduction in carbon dioxide emissions.

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[30] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review, July 2011*. *See* http://www.eia.gov/totalenergy/data/monthly/pdf/sec3_3.pdf (last accessed August 30, 2011).

[31] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review, July 2011*. *See* http://www.eia.gov/totalenergy/data/monthly/pdf/sec3_7.pdf (last accessed August 30, 2011).

[32] *Ibid.*

[33] U.S. Department of Energy, Energy Information Administration, *Weekly Retail and Gasoline Diesel Prices*. *See* http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_m.htm (last accessed, August 30, 2011).

[34] U.S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, *Quick Find: Vehicle Miles of Travel*, Table VM-2 (2006 and 2008). *Available at* http://www.fhwa.dot.gov/policyinformation/quickfinddata/qftravel.cfm (last accessed August 30, 2011).

[35] U.S. Department of Energy, Energy Information Administration, *International Energy Outlook 2010*, Table A5 (p. 150). *Available at* http://www.eia.gov/oiaf/ieo/pdf/0484%282010%29.pdf (last accessed August 30, 2011).

[36] IPCC 2007: Climate Change 2007: Synthesis Report: Contributions of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Core writing team, Pachauri, R.K. and Reisinger, A. 9eds.)] (Published by the Intergovernmental Panel on Climate Change, 2008). A*vailable at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf (last accessed August 30, 2011).

Energy is an essential input to the U.S. economy, and having a strong economy is essential to maintaining and strengthening our National security. Secure, reliable, and affordable energy sources are fundamental to economic stability and development. Rising energy demand poses a challenge to energy security, given increased reliance on global energy markets. As noted above, approximately half of the petroleum consumed in the U.S. is imported.

Conserving energy, especially reducing the Nation's dependence on petroleum, benefits the U.S. in several ways. Improving energy efficiency has benefits for economic growth and the environment, as well as other benefits, such as reducing pollution and improving security of energy supply. More specifically, reducing total petroleum use decreases our economy's vulnerability to oil price shocks. Reducing dependence on oil imports from regions with uncertain conditions enhances our energy security and can reduce the flow of oil profits to certain states now hostile to the U.S.

This CAFE Notice of Proposed Rulemaking encourages conservation of petroleum for transportation by the application of broader use of fuel saving technologies, resulting in more fuel-efficient vehicles, *i.e.*, vehicles requiring less fuel consumption per unit mile.

Table II-1 presents historical trend data and projections of the production and consumption of petroleum. Increases in domestic petroleum production are expected through 2035 as technological advances further the economic recoverability of oil from conventional and unconventional resources. Despite the projected increase in domestic production, by 2035 the U.S. is expected to remain reliant on foreign sources for over 40 percent of its oil needs.

Although not shown in Table II-1, the U.S. petroleum consumption is equivalent to U.S. petroleum supply. The Energy Information Administration's measure of U.S. petroleum supply exceeds the sum of domestic production and net imports because the EIA's measure of total supply includes renewable fuel and oxygenate plant net production, refinery and blender net production, changes in suppliers' reserve stocks, and adjustments for crude oil, fuel ethanol, motor gasoline blending components, and distillate fuel oil.

Table II-1

Petroleum Production and Supply
(Million Barrels per Day)

	Domestic Petroleum Production[37]	**Net Petroleum Imports**[38]	**U.S. Petroleum Consumption**[39]	**World Petroleum Consumption**[40]	**Net Imports as a Share of U.S. Consumption**[41]
1975	10.0	5.8	16.3	56.2	35.8%
1985	10.6	4.3	15.7	60.1	27.3%
1995	8.3	7.9	17.7	70.1	44.5%
2005	6.9	12.5	20.8	84.1	60.3%
2009	7.3	9.7	18.8	84.3	51.5%
DOE Predictions[42, 43]					
2015	8.0	9.8	20.4	88.7	48.1%
2025	8.6	9.1	21.0	97.6	43.2%
2035	8.9	8.9	21.9	110.6	40.5%

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[37] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review, July 2011*. *See* http://www.eia.gov/totalenergy/data/monthly/pdf/sec3_3.pdf (last accessed August 30, 2011).

[38] *Ibid.*

[39] *Ibid.*

[40] U.S. Department of Energy, Energy Information Administration, *International Energy Statistics*, Total Petroleum Consumption. *See* http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=5&pid=5&aid=2 (last accessed, August 30, 2011).

[41] U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review, July 2011*. *See* http://www.eia.gov/totalenergy/data/monthly/pdf/sec3_7.pdf (last accessed July 29, 2011).

[42] Source of Predictions of Domestic Petroleum Production, Net Petroleum Imports, and U.S. Petroleum Consumption: U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2011*, Table A11 (p. 137). *Available at* http://www.eia.gov/forecasts/aeo/pdf/0383%282011%29.pdf (last accessed August 30, 2011).

[43] Source of Predictions of World Petroleum Consumption: U.S. Department of Energy, Energy Information Administration, *International Energy Outlook 2010*, Table A5 (p. 150). *Available at* http://www.eia.gov/oiaf/ieo/pdf/0484%282010%29.pdf (last accessed August 30, 2011).

Table II-2 shows that light vehicle petroleum consumption made up 74.1 percent of all transportation petroleum consumption in 2009. Therefore, reductions in light vehicle petroleum consumption resulting from increases in CAFE fuel economy standards will substantively support the Nation's efforts to conserve energy.

Table II-2

Petroleum

Transportation Consumption by Mode
(Thousand Barrels per Day)[44]

	Passenger Cars	**Light Trucks**	**Total Light Vehicles**	**Total Transportation**	**Light Vehicles as % of Trans.**
1975	4,836	1,245	6,081	8,472	71.8%
1985	4,665	1,785	6,450	9,536	67.6%
1995	4,440	2,975	7,415	11,346	65.4%
2005	5,050	3,840	8,890	14,020	63.4%
2009	4,662	4,019	8,681	11,708	74.1%

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[44] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, *Transportation Energy Data Book*, Table 1.13. *Available at* http://cta.ornl.gov/data/chapter1.shtml (last accessed August 30, 2011).

III. BASELINE AND ALTERNATIVES

A. The Baseline Vehicle Fleet

1. Why establish a baseline vehicle fleet?

In order to calculate the impacts of the final rule, it is necessary to estimate the composition of the future vehicle fleet absent the final CAFE standards in order to conduct comparisons. EPA in consultation with NHTSA developed a comparison fleet in two parts. The first step was to develop a baseline fleet based on model year 2008 data. The 2008-based fleet is created in order to track the volumes and types of fuel economy-improving technologies which are already present in today's fleet. Creating a 2008-based 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 2008-based fleet sales into MYs 2017-2025. This is called the reference fleet, and it represents an attempt to predict the fleet that would exist in MYs 2017-2025 without the MY2009-2010, MY2011, or MY2012-2016 rules. The third step was to add technologies to that fleet such that each manufacturer's average car and truck CO_2 levels are in compliance with their MY 2016 CAFE standards proposed in this rule, assuming that manufacturers would not make fuel economy improvements beyond what is required by the MY 2016 standards. This final "reference fleet" is the light duty fleet estimated to exist in MYs 2017-2025 without the final CAFE standards. All of the agency's estimates of fuel economy improvements, costs, and societal impacts are developed in relation to the respective reference fleets.

2. How was the 2008-based vehicle fleet developed?

The baseline that EPA developed in consultation with NHTSA for the 2012-2016 final rule was comprised of model year 2008 CAFE compliance data (specifically, individual vehicles with sales volumes disaggregated at the level of specific engine/transmission combinations) submitted by manufacturers to EPA, in part because full MY 2009 data was not available at the time. For this NPRM, the agencies chose again to use MY 2008 vehicle data as the basis of the baseline fleet, but for different reasons than in the 2012-2016 final rule. First, MY 2008 is now the most recent model year for which the industry had what the agencies would consider to be "normal" sales. Complete MY 2009 data is now available for the industry, but the agencies believe that the model year was disrupted by the economic downturn and the bankruptcies of both General Motors and Chrysler. CAFE compliance data shows that there was a significant reduction in the number of vehicles sold by both companies and by the industry as a whole. These abnormalities led the agencies to conclude that MY 2009 data was likely not representative for projecting the future fleet for purposes of this analysis. And second, while MY 2010 data is likely more representative for projecting the future fleet, it was not complete and available in time for it to be used for the NPRM analysis. Therefore, for purposes of the NPRM analysis, the agencies chose to use MY 2008 CAFE compliance data for the baseline since it was the latest, most representative transparent data set that we had available. More details about how the agencies constructed this baseline fleet can be found in Chapter 1.2 of the Joint TSD. However, the agencies plan to use the MY 2010 data, if available, to develop an updated market forecast for use in the final rule. If and when the MY 2010 data becomes available, the agencies will place a copy of this data into each agencies' docket.

3. How was the projected MY 2017-2025 fleet (the reference fleet) developed?

EPA and NHTSA have based the projection of total car and total light truck sales for MYs 2017-2025 on projections made by the Department of Energy's Energy Information Administration (EIA). EIA publishes a mid-term projection of national energy use called the Annual Energy Outlook (AEO). This projection utilizes a number of technical and econometric models which are designed to reflect both economic and regulatory conditions expected to exist in the future. In support of its projection of fuel use by light-duty vehicles, EIA projects sales of new cars and light trucks.

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 publishes a projection of national energy use annually called the Annual Energy Outlook (AEO).[45] EIA published its Early Annual Energy Outlook for 2011 in December 2010. EIA released updated data to NHTSA in February (Interim AEO). The final release of AEO for 2011 came out in April 2011, but by that time EPA/NHTSA had already prepared modeling runs for potential 2017-2025 standards using the interim data release to NHTSA. EPA and NHTSA will use the newest version of AEO available in projecting the reference fleet for the final rule.

Similar to the analyses supporting the MYs 2012-2016 rulemaking, 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, NEMS methodology includes shifting vehicle sales volume, starting after 2007, away from fleets with lower fuel economy (the light-truck fleet) towards vehicles with higher fuel economies (the passenger car fleet) in order to facilitate compliance with CAFE and GHG MYs 2012-2016 standards.

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 proposed rules assuming manufacturers will not change fleet composition as a compliance strategy, as opposed to changes that might happen due to market forces), the Interim AEO 2011-projected shift in passenger car market share as a result of required fuel economy improvements creates a circularity. Therefore, for the current analysis, the agencies developed a new projection of passenger car and light truck sales shares by running scenarios from the Interim AEO 2011 reference case that first deactivate the above-mentioned sales-volume shifting methodology and then hold post-2017 CAFE standards

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

constant at MY 2016 levels. This is referred to as the Unforced Reference Case. Incorporating these changes reduced the projected passenger car share of the light vehicle market by an average of about 5% during 2017-2025.

In 2017, car and light truck sales are projected to be 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 timeframe. 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.

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 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 for several reasons. One, CSM 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. 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 proposed standards.

The agencies combined the CSM forecast with data from other sources to create the reference fleet projections. The process of producing the 2017-2025 reference fleet involved combining the baseline fleet with the projection data. This was a complex multistep procedure, which is described below and in more detail in Chapter 1 of the Joint TSD. This procedure is the same as that used for the 2012-2016 rule.

We then projected the CSM forecasts for relative sales of cars and trucks by manufacturer and by market segment onto the total sales estimates of AEO 2011. Tables III.A.3-1 and III.A.3-2 show the resulting projections for the reference 2025 model year and compare these to actual sales that occurred in baseline 2008 model year. Both tables show sales using the traditional definition of cars and light trucks.

Table III A.3-1 Annual Sales of Light-Duty Vehicles by Manufacturer in 2008 and Estimated for 2025

	Cars		Light Trucks		Total	
	2008 MY	2025 MY	2008 MY	2025 MY	2008 MY	2025 MY
Aston Martin	1,370	1,182			1,370	1,182
BMW	291,796	405,256	61,324	145,409	353,120	550,665
Daimler	208,195	340,719	79,135	101,067	287,330	441,786
Fiat/Chrysler	542,003	381,829	1,119,397	394,070	1,661,400	775,899
Ford	654,539	989,401	1,116,354	1,235,185	1,770,893	2,224,586
Geely/Volvo	55,600	88,039	42,797	55,657	98,397	143,696
General Motors	1,350,211	1,395,849	1,744,977	1,802,094	3,095,188	3,197,943
Honda	899,498	1,233,439	612,281	664,579	1,511,779	1,898,018
Hyundai	270,293	479,443	120,734	365,943	391,027	845,386
Kia	145,863	260,649	135,589	199,787	281,452	460,436
Lotus	252	316			252	316
Mazda	191,326	250,553	111,220	117,619	302,546	368,172
Mitsubishi	76,701	54,092	24,028	55,600	100,729	109,692
Nissan	653,121	895,341	370,294	545,889	1,023,415	1,441,229
Porsche	18,909	40,696	18,797	11,219	37,706	51,915
Spyker/Saab	21,706	23,130	4,250	3,475	25,956	26,605
Subaru	85,629	230,101	112,952	101,592	198,581	331,692
Suzuki	68,720	96,728	45,938	27,800	114,658	124,528
Tata	9,596	65,418	55,584	56,805	65,180	122,223
Tesla	800	31,974			800	31,974
Toyota	1,143,696	1,942,012	1,067,804	1,376,057	2,211,500	3,318,069
Volkswagen	291,483	630,163	26,999	154,284	318,482	784,447
Total	6,981,307	9,836,330	6,870,454	7,414,129	13,851,761	17,250,459

Table III A.3-2 Annual Sales of Light-Duty Vehicles by Market Segment in 2008 and Estimated for 2025

Cars			Light Trucks		
	2008 MY	2025 MY		2008 MY	2025 MY
Full-Size Car	829,896	245,355	Full-Size Pickup	1,332,335	1,002,806
Luxury Car	1,048,341	1,637,410	Mid-Size Pickup	452,013	431,272
Mid-Size Car	2,103,108	2,713,078	Full-Size Van	33,384	88,572
Mini Car	617,902	1,606,114	Mid-Size Van	719,529	839,452
Small Car	1,912,736	2,826,190	Mid-Size MAV*	110,353	548,457
Specialty Car	469,324	808,183	Small MAV	231,265	239,065
			Full-Size SUV*	559,160	46,978
			Mid-Size SUV	436,080	338,849
			Small SUV	196,424	71,827
			Full-Size CUV*	264,717	671,665
			Mid-Size CUV	923,165	1,259,483
			Small CUV	1,612,029	1,875,703
Total Sales**	6,981,307	9,836,330		6,870,454	7,414,129

* MAV – Multi-Activity Vehicle, SUV – Sport Utility Vehicle, CUV – Crossover Utility Vehicle
**Total Sales are based on the classic Car/Truck definition.

Determining which traditionally-defined trucks will be defined as cars for purposes of this analysis using the revised definition established by NHTSA for MYs 2011 and beyond requires more detailed information about each vehicle model. This is described in greater detail in Chapter 1 of the TSD.

The forecasts obtained from CSM provided estimates of car and truck sales by segment and by manufacturer, but not by manufacturer for each market segment. Therefore, NHTSA and EPA needed other information on which to base these more detailed projected market splits. For this task, the agencies used as a starting point each manufacturer’s sales by market segment from model year 2008, which is the baseline fleet. Because of the larger number of segments in the truck market, the agencies used slightly different methodologies for cars and trucks.
The first step for both cars and trucks was to break down each manufacturer’s 2008 sales according to the market segment definitions used by CSM. For example, the agencies found that Ford’s cars sales in 2008 were broken down as shown in Table III A.3-3:

Table III A.3-3 Breakdown of Ford's 2008 Car Sales

Full-size cars	160,857 units
Mid-size Cars	170,399 units
Small/Compact Cars	180,249 units
Subcompact/Mini Cars	None
Luxury cars	87,272 units
Specialty cars	110,805 units

EPA and NHTSA then adjusted each manufacturer's sales of each of its car segments (and truck segments, separately) so that the manufacturer's total sales of cars (and trucks) matched the total estimated for each future model year based on AEO and CSM forecasts. For example, as indicated in Table III A. 3-3, Ford's total car sales in 2008 were 709,583 units, while the agencies project that they will increase to 1,222,532 units by 2025. This represents an increase of 72.3 percent. Thus, the agencies increased the 2008 sales of each Ford car segment by 72.3 percent. This produced estimates of future sales which matched total car and truck sales per AEO and the manufacturer breakdowns per CSM. However, the sales splits by market segment would not necessarily match those of CSM (shown for 2025 in Table III A.3-1).

In order to adjust the market segment mix for cars, the agencies first adjusted sales of luxury, specialty and other cars. Since the total sales of cars for each manufacturer were already set, any changes in the sales of one car segment had to be compensated by the opposite change in another segment. For the luxury, specialty and other car segments, it is not clear how changes in sales would be compensated. For example, if luxury car sales decreased, would sales of full-size cars increase, mid-size cars, and so on? The agencies have assumed that any changes in the sales of cars within these three segments were compensated for by proportional changes in the sales of the other four car segments. For example, for 2025, the figures in Table III.A.3-2 indicate that luxury car sales in 2025 are 1,633,410 units. Luxury car sales are 1,048,341 units in 2008. However, after adjusting 2008 car sales by the change in total car sales for 2025 projected by EIA and a change in manufacturer market share per CSM, luxury car sales decreased to 1,539,165 units. Thus, overall for 2025, luxury car sales had to increase by 98,245 units or 6 percent. The agencies accordingly increased the luxury car sales by each manufacturer by this percentage. The absolute decrease in luxury car sales was spread across sales of full-size, mid-size, compact and subcompact cars in proportion to each manufacturer's sales in these segments in 2008. The same adjustment process was used for specialty cars and the "other cars" segment defined by CSM.

The agencies used a slightly different approach to adjust for changing sales of the remaining four car segments. Starting with full-size cars, the agencies again determined the overall percentage change that needed to occur in future year full-size car sales after 1) adjusting for total sales per AEO 2010, 2) adjusting for manufacturer sales mix per CSM and 3) adjusting the luxury, specialty and other car segments, in order to meet the segment sales mix per CSM. Sales of each manufacturer's large cars were adjusted by this percentage. However, instead of spreading this change over the remaining three segments, the agencies assigned the entire change to mid-size vehicles. The agencies did so because the CSM data followed the trend of increasing volumes of smaller cars while reducing volumes of larger cars. If a consumer had previously purchased a full-size car, we thought it unlikely that their next purchase would decrease by two size categories, down to a subcompact. It seemed more reasonable to project that they would drop one vehicle size category smaller. Thus, the change in each manufacturer's sales of full-size cars was matched by an opposite change (in absolute units sold) in mid-size cars.

The same process was then applied to mid-size cars, with the change in mid-size car sales being matched by an opposite change in compact car sales. This process was repeated one more time for compact car sales, with changes in sales in this segment being matched by the opposite change in the sales of subcompacts. The overall result was a projection of car sales for model years 2017-2025--the reference fleet--which matched the total sales projections of the AEO forecast and the manufacturer and segment splits of the CSM forecast.

As mentioned above, the agencies applied a slightly different process to truck sales, because the agencies could not confidently project how the change in sales from one segment preferentially went to or came from another particular segment. Some trend from larger vehicles to smaller vehicles would have been possible. However, the CSM forecasts indicated large changes in total sport utility vehicle, multi-activity vehicle and cross-over sales which could not be connected. Thus, the agencies applied an iterative, but straightforward process for adjusting 2008 truck sales to match the AEO and CSM forecasts. The first three steps were exactly the same as for cars. EPA and NHTSA broke down each manufacturer's truck sales into the truck segments as defined by CSM. The agencies then adjusted all manufacturers' truck segment sales by the same factor so that total truck sales in each model year matched AEO projections for truck sales by model year. The agencies then adjusted each manufacturer's truck sales by segment proportionally so that each manufacturer's percentage of total truck sales matched that forecast by CSM. This again left the need to adjust truck sales by segment to match the CSM forecast for each model year.

In the fourth step, the agencies adjusted the sales of each truck segment by a common factor so that total sales for that segment matched the combination of the AEO and CSM forecasts. For example, projected sales of large pickups across all manufacturers were 932,610 units in 2025 after adjusting total sales to match AEO's forecast and adjusting each manufacturer's truck sales to match CSM's forecast for the breakdown of sales by manufacturer. Applying CSM's forecast of the large pickup segment of truck sales to AEO's total sales forecast indicated total large pickup sales of 1,002,086 units. Thus, we increased each manufacturer's sales of large pickups by 7 percent. The agencies applied the same type of adjustment to all the other truck segments at the same time. The result was a set of sales projections which matched AEO's total truck sales projection and CSM's market segment forecast. However, after this step, sales by manufacturer no longer met CSM's forecast. Thus, we repeated step three and adjusted each manufacturer's truck sales so that they met CSM's forecast. The sales of each truck segment (by manufacturer) were adjusted by the same factor. The resulting sales projection matched AEO's total truck sales projection and CSM's manufacturer forecast, but sales by market segment no longer met CSM's forecast. However, the difference between the sales projections after this fifth step was closer to CSM's market segment forecast than it was after step three. In other words, the sales projection was converging to the desired result. The agencies repeated these adjustments, matching manufacturer sales mix in one step and then market segment in the next a total of 19 times. At this point, we were able to match the market segment splits exactly and the manufacturer splits were within 0.1 percent of our goal, which is well within the needs of this analysis.

The next step in developing the reference fleets was to characterize the vehicles within each manufacturer-segment combination. In large part, this was based on the characterization of the specific vehicle models sold in 2008 -- *i.e.*, the vehicles comprising the baseline fleet. EPA and NHTSA chose to base our estimates of detailed vehicle characteristics on 2008 sales for several reasons. One, these vehicle characteristics are not confidential and can thus be published here for careful review by interested parties. Two, because it is constructed beginning with actual sales data, this vehicle fleet is limited to vehicle models known to satisfy consumer demands in light of price, utility, performance, safety, and other vehicle attributes.

As noted above, the agencies gathered most of the information about the 2008 baseline vehicle fleet from EPA's emission certification and fuel economy database. The data obtained from this source included vehicle production volume, fuel economy, engine size, number of engine cylinders, transmission type, fuel type, etc. EPA's certification database does not include a detailed description of the types of fuel economy-improving/CO_2-reducing technologies considered in this final rule. Thus, the agencies augmented this description with publicly available data which includes more complete technology descriptions from Ward's Automotive Group.[46] In a few instances when required vehicle information (such as vehicle footprint) was not available from these two sources, the agencies obtained this information from publicly accessible internet sites such as Motortrend.com and Edmunds.com.[47]

The projections of future car and truck sales described above apply to each manufacturer's sales by market segment. The EPA emissions certification sales data are available at a much finer level of detail, essentially vehicle configuration. As mentioned above, the agencies placed each vehicle in the EPA certification database into one of the CSM market segments. The agencies then totaled the sales by each manufacturer for each market segment. If the combination of AEO and CSM forecasts indicated an increase in a given manufacturer's sales of a particular market segment, then the sales of all the individual vehicle configurations were adjusted by the same factor. For example,

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[46] Note that WardsAuto.com is a fee-based service, but all information is public to subscribers.

[47] Motortrend.com and Edmunds.com are free, no-fee internet sites.

if the Prius represented 30 percent of Toyota's sales of compact cars in 2008 and Toyota's sales of compact cars in 2025 was projected to double by 2025, then the sales of the Prius were doubled, and the Prius sales in 2025 remained 30 percent of Toyota's compact car sales.

For the final rule, the agencies intend to use a more recent version of EIAs AEO, and we also will consider using MY 2010 for the baseline, and potentially an updated future market forecast.

4. How is the development of the baseline fleet for this rule different from the baseline fleet that NHTSA used for the MY 2012-2016 (May 2010) final rule?

The development of the baseline fleet for this rulemaking utilizes the same procedures used in the development of the baseline fleet for the MY 2012-2016 rulemaking. Unlike that rulemaking we are not making the radical change from using product plan based data to public data. We are using an updated AEO forecast and an updated CSM forecast, but are using basically the same MY 2008 based file as the starting point. Most differences are in input assumptions rather than the basic approach and methodology. These include changes in various macro economic assumptions underlying the AEO and CSM forecasts and the use of the AEO Unforced Reference Case.

Another change in the market input data from the last rulemaking involved our redefinition of the list of manufacturers to account for realignment taking place within the industry. The reported results supporting this rulemaking recognize the fact that Volvo vehicles are no longer a part of Ford, but are reported as a separate company, Geely; that Saab vehicles are no longer part of GM, but are reported as part of Spyker; and that Chrysler, along with Ferrari and Maserati are reported as Fiat.

In addition low volume, specialty manufacturers omitted from the analysis supporting the MY 2012-2016 rulemaking have been included in the analysis supporting this rulemaking. These include Aston Martin, Lotus and Tesla.

The agencies' reasons for not relying on product plan data for the development of the baseline fleet were discussed in the Regulatory Impact Analysis[48] for the MY 2012-MY 2016 rulemaking and are summarized below. The agencies could find no compelling reason for abandoning the approach used in that rulemaking in developing the baseline fleet for the current rulemaking.

The RIA discusses the advantages and disadvantages of the market forecast approach used by the agencies. Two major disadvantages were noted as follows. First, the agencies' current market forecast includes some vehicles for which manufacturers have announced plans for elimination or drastic production cuts. However, although the

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[48] *Final Regulatory Impact Analysis, Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks,* Office of Regulatory Analysis and Evaluation and National Center for Statistics and Analysis, National Highway Traffic Safety Administration , U.S. Department of Transportation, March 2010. http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE_2012-2016_FRIA_04012010.pdf (last accessed November 13, 2011)

agencies recognize that these specific vehicles will be discontinued, we continue to include them in the market forecast because they are useful as a surrogate for successor vehicles that may appear in the rulemaking time frame to replace the discontinued vehicles in that market segment.

Second, the agencies' market forecast does not include several MY 2009 or 2010 vehicles, such as the Honda Insight, the Hyundai Genesis and the Toyota Venza and some forthcoming vehicle models, such as the Chevrolet Volt, since the starting point for defining specific vehicle models in the reference fleet was Model Year 2008. It has been suggested that the agencies' omission of known future vehicles and technologies in the reference fleet causes inaccuracies. Because the agencies' analysis examines the costs and benefits of progressively adding technology to manufacturers' fleets, the omission of future vehicles and technologies primarily affects how much additional technology (and, therefore, how much incremental cost and benefit) is available relative to the point at which the agencies' examination of potential new standards begins. Thus, in fact, the omission only reflects the reference fleet, rather than the agencies' conclusions regarding how stringent the standards should be. Considering the incremental nature of the agencies' analysis, and the counterbalancing aspects of potentially omitted technology in the reference fleet, the agencies believe their determination of the stringency of new standards has not been impacted by any such omissions. However, omitting the known future vehicles and technologies may lead to an overstatement of the benefits and costs of the rule. For example, in the 2008-baseline assumption we assume the profitable technologies to place on MY2017-2025 vehicles are not provided by manufacturers. Such technologies include some transmission technologies such as the "6sp DCT-dry", which we forecast actually have negative costs for the manufacturer.

There are several advantages to the approach used by the agencies in developing the reference fleet for this rulemaking. Most importantly, the market forecast is transparent. The information sources used to develop the market forecast are all either in the public domain or available commercially. In addition, by developing baseline and reference fleets from common sources, the agencies have been able to avoid some errors—perhaps related to interpretation of requests—that have been observed in past responses to NHTSA's requests for product plan data. An additional advantage of the approach used for this proposal is a consistent projection of the change in fuel economy and CO_2 emissions across the various vehicles from the application of new technology. With the approach used for this rulemaking, the baseline market data comes from actual vehicles (on the road today) which have actual fuel economy test data (in contrast to manufacturer estimates of future product fuel economy) – so there is no question what is the basis for the fuel economy or CO_2 performance of the baseline market data as it is. However, the agencies recognize the additional information about future products contained in manufacturers' confidential data.

The agencies have carefully considered these advantages and disadvantages of using a market forecast derived from public and commercial sources rather than from manufacturers' product plans, and we believe that the advantages outweigh the disadvantages for the purpose of proposing standards for model years 2017-2025.

5. How is this baseline different quantitatively from the baseline that NHTSA used for the MY 2012-2016 (May 2010) final rule?

As discussed above, the current baseline was developed from adjusted MY 2008 compliance data and covers MY 2017-2025. This section describes, for the reader's comparison, some of the differences between the current baseline and the MY 2012-2016 CAFE rule baseline. This comparison provides a basis for understanding general characteristics and measures of the difference between the two baselines. The current baseline, while developed using the same methods as the baseline used for MY 2012-2016 rulemaking, reflects updates to the underlying commercially-available forecast of manufacturer and market segment shares of the future light vehicle market. The differences are in input assumptions rather than the basic approach and methodology. It also includes changes in various macro economic assumptions underlying the AEO forecasts and the use of the AEO Unforced Reference Case. Another change in the market input data from the last rulemaking involved our redefinition of the list of manufacturers to account for realignment taking place within the industry.

Estimated vehicle sales:

The sales forecasts, based on the Energy Information Administration's (EIA's) Early Annual Energy Outlook for 2011 (Interim AEO 2011), used in the current baseline indicate that the total number of light vehicles expected to be sold during MYs 2012-2016 is 79 million, or about 15.8 million vehicles annually. NHTSA's MY 2012-2016 final rule forecast, based on AEO 2010, of the total number of light vehicles likely to be sold during MY 2012 through MY 2016 was 80 million, or about 16 million vehicles annually. Light trucks are expected to make up 37 percent of the MY 2016 baseline market forecast in the current baseline, compared to 34 percent of the baseline market forecast in the MY 2012-2016 final rule. These changes in both the overall size of the light vehicle market and the relative market shares of passenger cars and light trucks reflect changes in the economic forecast underlying AEO, changes in AEO's forecast of future fuel prices, and use of the Unforced Reference Case.

Estimated manufacturer market shares:

These changes are reflected below in Table III A.5-1, which shows the agency's sales forecasts for passenger cars and light trucks under the current baseline and the MY 2012-2016 final rule. There has been a general decrease in MY 2016 forecast overall sales and for all manufacturers, with the exception of Chrysler, when the current baseline is compared to that used in the MY 2012-2016 rulemaking. There were no significant shifts in manufacturers' market shares between the two baselines. The effect of including the low volume specialty manufacturers and accounting for known corporate realignments in the current baseline appear to be negligible. There has been a shift in the shares of passenger and non passenger vehicles as would be expected given that the agency is relying on different underlying assumptions as discussed above and in Chapter 1 of the joint TSD.

Table III A.5-1. Sales Forecasts (Production for U.S. Sale in MY 2016, Thousand Units)

Manufacturer	**MY 2012-2016 Final Rule[49]**		**Current Baseline**	
	Passenger Car	**Light Truck**	**Passenger Car**	**Light Truck**
Aston Martin			1	
BMW	423	171	383	184
Daimler	271	126	245	136
Fiat/Chrysler	400	462	392	498
Ford	1,559	911	1,393	930
Geely/Volvo			94	50
General Motors	1,514	1,342	1,391	1,444
Honda	930	545	862	588
Hyundai	518	92	489	99
Kia	548	115	512	124
Lotus			0.3	
Mazda	420	72	393	78
Mitsubishi	83	55	80	60
Nissan	946	381	869	410
Porsche	33	17	30	18
Spyker/Saab			18	2
Subaru	207	117	236	74
Suzuki	103	20	94	21
Tata	65	42	59	46
Tesla			27	
Toyota	2,226	1,077	2,043	1,159
Volkswagen	583	124	528	134
Total	10,832	5,669	10,139	6,055

<u>Estimated achieved fuel economy levels</u>:
The current baseline market forecast shows industry-wide average fuel economy levels somewhat lower in MY 2016 than shown in the baseline market forecast for the MY 2012-2016 rulemaking. Under the current baseline, average fuel economy for MY 2016 is 27.0 mpg, versus 27.3 mpg under the baseline in the MY 2012-2016 rulemaking. The

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[49] Again, Aston Martin, Alfa Romeo, Ferrari, Maserati, Lotus and Tesla were not included in the baseline of the MY 2012-2016 rulemaking; Volvo vehicles were reported under Ford and Saab vehicles were reported under GM; and Chrysler was reported as a separate company whereas now it is reported as part of Fiat and includes Alfa Romeo, Ferrari, and Maserati.

0.3 mpg change relative to the MY 2012-2016 rulemaking's baseline is the result of changes in the shares of passenger and non passenger vehicles in the MY 2016 market as noted above.

These differences are shown in greater detail below in Table III A.5-1, which shows manufacturer-specific CAFE levels (not counting FFV credits that some manufacturers expect to earn) from the current baseline versus the MY 2012-2016 rulemaking baseline for passenger cars and light trucks. Table III A.5-2 shows the combined averages of these planned CAFE levels in the respective baseline fleets. These tables demonstrate that there are no significant differences in CAFE for passenger or non passenger vehicles at the manufacturer level between the current baseline and the MY 2012-2016 rulemaking baseline. The differences become more significant at the manufacturer level when combined CAFÉ levels are considered. Here we see a general decline in CAFE at the manufacturer level due to the increased share of light trucks. Because the agencies have, as for the MY 2012-2016 rulemaking, based this market forecast on vehicles in the MY 2008 fleet, these changes in CAFE levels reflect changes in vehicle mix, not changes in the fuel economy achieved by individual vehicle models.

Table III A.5-2. Current Baseline CAFE Levels in MY 2016 versus MY 2012-2016 Rule Making CAFE Levels (Passenger Car and Light Truck)

Manufacturer	**MY 2012-2016 Final Rule**[50]		**Current Baseline**	
	Passenger Car	**Light Truck**	**Passenger Car**	**Light Truck**
Aston Martin			18.83	
BMW	27.19	23.04	27.19	23.03
Daimler	25.25	21.12	25.50	21.13
Fiat/Chrysler	28.69	22.19	27.74	22.19
Ford	28.14	21.31	28.24	21.32
Geely/Volvo			25.89	21.08
General Motors	28.42	21.45	28.38	21.45
Honda	33.98	25.05	33.83	25.02
Hyundai	32.02	24.30	31.74	24.29
Kia	32.98	23.74	32.70	23.74
Lotus			29.66	
Mazda	30.94	26.41	30.77	26.40
Mitsubishi	28.94	23.59	28.86	23.57
Nissan	32.04	22.11	31.98	22.10
Porsche	26.22	19.98	26.22	19.98
Spyker/Saab			26.54	19.79
Subaru	29.44	26.91	29.59	27.37
Suzuki	30.84	23.29	30.77	23.29
Tata	24.58	19.74	24.58	19.71
Tesla			244.00	
Toyota	35.33	24.25	35.22	24.26
Volkswagen	28.99	20.23	28.90	20.24
Total/Average	30.73	22.59	30.65	22.56

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[50] Again, Aston Martin, Alfa Romeo, Ferrari, Maserati, Lotus and Tesla were not included in the baseline of the MY 2012-2016 rulemaking; Volvo vehicles were reported under Ford and Saab vehicles were reported under GM; and Chrysler was reported as a separate company whereas now it is reported as part of Fiat and includes Alfa Romeo, Ferrari, and Maserati.

Table III A.5-3. Current Baseline CAFE Levels in MY 2016 versus MY 2012-2016 Rule Making CAFE Levels (Combined)

Manufacturer	**MY 2012-2016 Final Rule** [51]	**Current Baseline**
Aston Martin		18.83
BMW	25.85	25.68
Daimler	23.77	23.75
Fiat/Chrysler	24.79	24.33
Ford	25.17	24.99
Geely/Volvo		23.99
General Motors	24.66	24.37
Honda	30.03	29.61
Hyundai	30.56	30.18
Kia	30.89	30.46
Lotus		29.66
Mazda	30.18	29.95
Mitsubishi	26.53	26.33
Nissan	28.38	27.97
Porsche	23.74	23.48
Spyker/Saab		25.70
Subaru	28.47	29.03
Suzuki	29.30	29.04
Tata	22.42	22.19
Tesla		244.00
Toyota	30.75	30.27
Volkswagen	26.94	26.60
Total/Average	27.34	27.03

6. How does manufacturer product plan data factor into the baseline used in this final rule?

In December 2010, NHTSA requested that manufacturers provide information regarding future product plans, as well as information regarding the context for those plans (e.g., estimates of future fuel prices), and estimates of the future availability, cost, and efficacy

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[51] Again, Aston Martin, Alfa Romeo, Ferrari, Maserati, Lotus and Tesla were not included in the baseline of the MY 2012-2016 rulemaking; Volvo vehicles were reported under Ford and Saab vehicles were reported under GM; and Chrysler was reported as a separate company whereas now it is reported as part of Fiat and includes Alfa Romeo, Ferrari, and Maserati.

of fuel-saving technologies.[52] The purpose of this request was to acquire updated information regarding vehicle manufacturers' future product plans to assist the agency in assessing what corporate average fuel economy (CAFE) standards should be established for passenger cars and light trucks manufactured in model years 2017 and beyond. The request was being issued in preparation for today's joint Notice of Proposed Rulemaking regarding future CAFE and greenhouse gas (GHG) standards.

To assist the agency in analyzing potential CAFE standards for MYs 2017 and beyond, NHTSA requested any updates to product plans previously provided by vehicle manufacturers, as well as production data through the recent past, including data about engines, transmissions, vehicle mass reduction technologies, and hybrid technologies for MY 2010 through MY 2025 passenger cars and light trucks and the assumptions underlying those plans.

NHTSA indicated that it requested information for MYs 2010-2025 primarily as a basis for subsequent discussions with individual manufacturers regarding their capabilities for the MYs 2017-2025 time frame as it worked to develop today's NPRM. NHTSA indicated that the information received would supplement other information to be used by NHTSA to develop a realistic forecast of the vehicle market in MY 2017 and beyond, and to evaluate what technologies may feasibly be applied by manufacturers to achieve compliance with potential future standards. NHTSA further indicated that information regarding later model years could help the agency gain a better understanding of how manufacturers' plans through MY 2025 relate to their longer-term expectations regarding foreseeable regulatory requirements, market trends, and prospects for more advanced technologies (such as HCCI engines, dual loop cooled EGR, plug-in hybrid, electric, and fuel cell vehicles, among others).

NHTSA also indicated that it would consider information regarding the model years requested when considering manufacturers' planned schedules for redesigning and freshening their products, in order to examine how manufacturers anticipate tying technology introduction to product design schedules. In addition, the agency requested information regarding manufacturers' estimates of the future vehicle population, and fuel economy improvements and incremental costs attributed to technologies reflected in those plans.

Given the importance that responses to this request for comment may have in informing NHTSA's proposed CAFE rulemaking, whether as part of the basis for the standards or as an independent check on them, NHTSA requested that commenters fully respond to each question, particularly by providing information regarding the basis for technology costs and effectiveness estimates.

Although NHTSA practice has typically been to request product plan information reaching several years beyond the end of the anticipated rulemaking time frame in order to provide this context, many manufacturers submitting comments in the past have provided relatively little detail in response for those later model years. Considering past responses to these requests, NHTSA expected that most manufacturers' product plans

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[52] 75 FR 80430

would be well defined through approximately 2015, somewhat less defined through approximately 2020, and thereafter, increasingly fluid and open to change. As NHTSA and EPA are working jointly to consider standards that cover MYs 2017-2025, we requested that manufacturers provide as much information as they can, spanning as many of these model years as feasible, and also summarize major sources of uncertainty. For example, if a manufacturer's plans depend significantly on fuel prices, we requested that the manufacturer indicate which fuel prices they have assumed, as well as what general differences in product plans could be expected given significantly lower or higher future fuel prices. Also, as fuel economy regulations are not defined beyond MY 2016, and GHG regulations currently do not change after MY 2016, it is expected that product plan information may be based on requirements continuing to reflect MY 2016 levels through MY 2025. However, if other assumptions have been used, NHTSA requested those assumptions be provided.

In addition, NHTSA noted that it would share the information submitted in response to this notice with the Environmental Protection Agency (EPA), and that doing so would facilitate NHTSA's and EPA's consideration of the appropriate factors to be used in establishing fuel economy and GHG standards, respectively, for MY 2017 and beyond. Both agencies must ensure that confidential information that is shared is protected from disclosure in accordance with their regulations and practices in this area.

In response to NHTSA’s request, Chrysler, Ford, General Motors, Mazda, Mitsubishi, and Porsche submitted product plans in February 2011. These plans contain detailed estimates—including fuel economy levels, technology content, other engineering characteristics, and sales volumes—of the fleets these manufacturers plan to produce for sale in the U.S. in the future. Three of these manufacturers provided plans through MY 2016; among the other manufacturers, plans extended through MYs 2015, 2020, and 2025. NHTSA believes these manufacturers’ submitted product plans reflect significant expenditure of effort and attention to detail. Before preparing today’s NPRM, NHTSA met with these manufacturers (and others) to discuss their capabilities, and the information provided in these product plans helped the agency to prepare for and more effectively question these manufacturers.

For CAFE rulemakings through March 2010 (in that case, for MY 2011), NHTSA used manufacturers’ product plans—and other information—to build market forecasts providing the foundation for the agency’s rulemaking analysis. The agency continues to believe that these market forecasts reflected the most technically sound forecasts the agency could have then developed for this purpose. Because the agency could not disclose confidential business information in manufacturers’ product plans, NHTSA provided summarized information, such as planned CAFE levels and technology application rates, rather than the fuel economy levels and technology content of specific vehicle model types.

In preparing the MY 2012-2016 rule jointly with EPA, NHTSA revisited this practice, and concluded that for that rulemaking, it was important that all reviewers have equal access to all details of NHTSA’s analysis. NHTSA provided this level of transparency by releasing not only the agency’s CAFE modeling system (a.k.a. “the Volpe model”), but also by releasing all model inputs and outputs for the agency's analysis. Therefore, NHTSA worked with EPA, as it did in preparing for analysis supporting today's proposal, to build a market forecast based on publicly- and commercially-available sources. NHTSA continues to believe that the potential technical benefits of relying on manufacturers' plans for future products are outweighed by the transparency gained in building a market forecast that does not rely on confidential business information.

7. How else is NHTSA considering looking at the baseline for the final rule?

NHTSA has also developed an alternative "market-driven" baseline which assumes that manufacturers may adopt some fuel-saving measures beyond what is required by the MY 2016 rule. This baseline, discussed in Section X, below, assumes that manufacturers will compare the cost of fuel-saving technologies to consumers to the fuel savings in the first year of operation and decide to voluntarily apply those technologies to their vehicles when benefits for the first year exceeded costs for the consumer. NHTSA seeks comment on whether this baseline more accurately predicts the likely state of the market in MY 2017 to 2025 than the flat baseline assumption, or whether even more fuel technologies would be likely to be adopted in the absence of the proposed rule.

NHTSA is also considering developing and using a vehicle choice model to estimate the extent to which sales volumes would shift in response to changes in vehicle prices and fuel economy levels. As discussed Chapter V, the agency is currently sponsoring research directed toward developing such a model. If that effort is successful, the agency will consider integrating the model into the CAFE modeling system and using the integrated system for future analysis of potential CAFE standards. If the agency does so, we expect that the vehicle choice model would impact estimated fleet composition not just under new CAFE standards, but also under baseline CAFE standards.

B. Alternatives examined by the agency, and why NHTSA is proposing the Preferred Alternative

1. What regulatory alternatives has NHTSA considered in this analysis, and why?

In developing the proposed MY 2017-25 standards, the agency has developed and examined a wide variety of alternatives. The No-Action Alternative assumes continuation of MY 2016 standards. All other alternatives begin with curves resulting from the agency's updated curve fitting analysis (discussed in Chapter V). Curves defining all regulatory alternatives have the same constrained linear form (linear on a fuel consumption basis), and define fuel economy targets applicable to each vehicle model, based on the vehicle's footprint:

Required CAFE level depends not only on the footprints of specific vehicle models, but also on the numbers of units produced for sale in the U.S.:

The curves defining fuel economy targets do not depend on fleet mix, and are therefore not subject to uncertainty because NHTSA cannot predict with certainty what mix of vehicle manufacturers will sell through MY 2025. However, future average required fuel economy levels cannot be predicted with certainty, because average fuel economy levels depend on fleet mix.

The agency selected a range of candidate curves that increased in stringency by 2% to 7% annually.[53] Thus, the majority of the alternatives considered in this rulemaking are defined as annual increases in curve stringency—2 percent per year, 3 percent per year, 4 percent per year, and so on. NHTSA believes that this approach clearly communicates the requirements of each alternative and allows us to identify alternatives that represent different ways to balance NHTSA's statutory requirements under EPCA/EISA. NHTSA has also estimated average required fuel economy levels under each alternative, but notes that these estimates are based on fleet mix projections that are subject to uncertainty.

Each of the listed alternatives represents, in part, a different way in which NHTSA could conceivably balance different policies and considerations in setting the standards. The agency needs to weigh and balance many factors, such as technological feasibility, economic practicability, including lead time considerations for the introduction of technologies and impacts on the auto industry, the impacts of the standards on fuel savings and CO_2 emissions, and fuel savings by consumers, as well as other relevant factors such as safety. For example, the 7% Alternative weighs energy conservation and climate change considerations more heavily and technological feasibility and economic practicability less heavily. In contrast, the 2% Alternative, the least stringent alternative (aside from the No-Action Alternative), places more weight on technological feasibility and economic practicability. The "feasibility" of the alternatives also may reflect differences and uncertainties in the way in which key economic (*e.g.*, the price of fuel and the social cost of carbon) and technological inputs could be assessed and estimated or valued. Some technologies will not be available for more than limited commercial use in earlier model years, and that even those technologies that could be more widely commercialized through MY 2025 cannot all be deployed on every vehicle model in MY 2017 but require a realistic schedule for more widespread commercialization to be within the realm of economically practicability. The preferred alternative, discussed below in Section B.2, represents the agency's tentative conclusion as to how these factors should be balanced to produce the maximum feasible standards for MYs 2017-2025.

In addition to the alternatives defined by curves with stringency that increases evenly at annual rates ranging from 2% to 7%, NHTSA is also considering alternatives developed using benefit-cost criteria. The agency emphasized benefit-cost-related alternatives in its

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[53] The fitted curves from NHTSA's analysis reflect the maximum application of most technologies, in order to adjust for differences in technologies in the MY 2008 fleet. Before applying these annual stringency increases, NHTSA adjusted these curves to levels that would produce the same average required fuel economy levels in MY 2016 as would the actual MY 2016 standards the agency recently promulgated.

rulemakings for MY 2008-2011 and, subsequently, MY 2011 standards. By including such alternatives in its analysis, the agency is providing a degree of analytical continuity between the two approaches to defining alternatives in an effort to illustrate the similarities and dissimilarities. To that end, we have included and analyzed two additional alternatives, one that sets standards at the point where net benefits are maximized (labeled "MNB" in the table below), and another that sets standards at the point at which total costs are most nearly equal to total benefits (labeled "TCTB" in the table below).[54] With respect to the first of those alternatives, we note that Executive Order 12866 focuses attention on an approach that maximizes net benefits. Further, since NHTSA has previously set attribute-based CAFE standards at the point at which net benefits are maximized, we believe it will be useful and informative to consider the potential impacts of that approach as compared to the new approach, which the agency also applied in 2010 for MYs 2012-2016.

All of the above alternatives were developed in terms of the 2-cycle test that has, to date, provided the basis for determining fuel economy levels used to calculate manufacturers' CAFE levels. EPA is responsible for determining these test procedures and calculation methods, and is today proposing to change fuel economy calculation methods to include adjustments reflecting any increases in the efficiency of automotive air conditioners. NHTSA and EPA have estimated the average extent to which manufacturers will apply such improvements, and NHTSA has adjusted all regulatory alternatives accordingly.

Table III.B.1-1. Estimated Average Adjustments (g/mi CO_2) Reflecting Air Conditioner Efficiency Increases

Model Years	Passenger Cars	Light Trucks
2017	5.0	5.0
2018	5.0	6.5
2019-2025	5.0	7.2

NHTSA applied these adjustments as follows:

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[54] The stringency indicated by each of these alternatives depends on the value of inputs to NHTSA's analysis. Results presented here for these two alternatives are based on NHTSA's reference case inputs, which underlie the central analysis of the proposed standards. In the accompanying FRIA, the agency presents the results of that analysis to explore the sensitivity of results to changes in key economic inputs. Because of numerous changes in model inputs (*e.g.*, discount rate, rebound effect, CO_2 value, technology cost estimates), our analysis often exhausts all available technologies before reaching the point at which total costs equal total benefits. In these cases, the stringency that exhausts all available technologies is considered. Also, because the agency's analysis "carries forward" technologies applied in one model year, and also simulates "multiyear planning" (manufacturers' early application of technology to facilitate compliance in later model years), the agency's estimates of the net benefit maximizing and "TCTB" stringencies are subject to interactions between model years.

Where $Target_{AC}$ is the fuel economy target reflecting AC adjustments, and the 8,887 grams of CO_2 per gallon reflects the characteristics of indolene, the test fuel used to certify the fuel economy of gasoline vehicles. In terms of coefficients defining CAFE standards, NHTSA applied the additive adjustment to the *Intercept*, *MinTarget*, and *MaxTarget* terms as follows:

For purposes of estimating the incremental effects of new CAFE standards, NHTSA defined a No-Action Alternative that assumed MY 2016 standards would remain in effect through MY 2025, and adjusted these standards based on the assumption that, on average, manufacturers would implement AC efficiency improvements reflecting a 4.8 g/mi adjustment. The following table presents the range of targets spanned by the resultant curves, as well as NHTSA's estimates of the resultant average required fuel economy levels. As discussed above, while curves are fixed, average required fuel economy levels depend on fleet composition, and are therefore subject to change. For example, the No-Action Alternative for light trucks is a curve (unchanging during MY 2017-2025) specifying a maximum fuel economy target (for the smallest light trucks) of 35.07 mpg, a minimum fuel economy target (for the largest light trucks) of 25.08 mpg, with targets decreasing between these limits as footprint increases. Based on the market agency's market forecast discussed above, NHTSA estimates that this curve would result in average required fuel economy levels that increase gradually from 29.31 mpg in MY 2017 to 39.44 mpg in MY2025, as the light truck market shifts gradually toward smaller vehicles.

Table III.B.1-2. No-Action Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	31.49 - 42.03 (38.54)	25.08 - 35.07 (29.31)	25.08 - 42.03 (34.54)
2018	31.49 - 42.03 (38.55)	25.08 - 35.07 (29.31)	25.08 - 42.03 (34.58)
2019	31.49 - 42.03 (38.56)	25.08 - 35.07 (29.33)	25.08 - 42.03 (34.65)
2020	31.49 - 42.03 (38.54)	25.08 - 35.07 (29.31)	25.08 - 42.03 (34.69)
2021	31.49 - 42.03 (38.55)	25.08 - 35.07 (29.31)	25.08 - 42.03 (34.71)
2022	31.49 - 42.03 (38.56)	25.08 - 35.07 (29.32)	25.08 - 42.03 (34.76)
2023	31.49 - 42.03 (38.55)	25.08 - 35.07 (29.36)	25.08 - 42.03 (34.83)
2024	31.49 - 42.03 (38.56)	25.08 - 35.07 (29.40)	25.08 - 42.03 (34.91)
2025	31.49 - 42.03 (38.58)	25.08 - 35.07 (29.44)	25.08 - 42.03 (34.98)

This table also shows that although there is no CAFE standard for the combined (passenger car and light truck) fleet, the lowest possible requirement would be 25.08 mpg (if the market shifted entirely to the very largest light trucks), the highest possible requirement would be 42.08 (if the market shifted entirely to the very smallest passenger cars), and NHTSA estimates that the overall average fuel economy required of the industry under the No Action Alternative increases gradually from 34.53 mpg in MY 2017 to 34.98 mpg in MY 2025, as the market gradually shifts toward away from light trucks and toward passenger cars.

The above table accounts for AC efficiency improvements NHTSA estimates manufacturers will apply under the No Action Alternative. NHTSA's actual MY 2012-2016 standards do not accommodate adjustments for such improvements, and setting aside those improvements, the results would be as summarized in the following table:

Table III.B.1-3. No-Action Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	30.96 - 41.09 (37.75)	24.74 - 34.42 (28.83)	24.74 - 41.09 (33.89)
2018	30.96 - 41.09 (37.76)	24.74 - 34.42 (28.84)	24.74 - 41.09 (33.94)
2019	30.96 - 41.09 (37.76)	24.74 - 34.42 (28.86)	24.74 - 41.09 (34.00)
2020	30.96 - 41.09 (37.74)	24.74 - 34.42 (28.84)	24.74 - 41.09 (34.04)
2021	30.96 - 41.09 (37.77)	24.74 - 34.42 (28.86)	24.74 - 41.09 (34.08)
2022	30.96 - 41.09 (37.78)	24.74 - 34.42 (28.86)	24.74 - 41.09 (34.12)
2023	30.96 - 41.09 (37.77)	24.74 - 34.42 (28.92)	24.74 - 41.09 (34.20)
2024	30.96 - 41.09 (37.77)	24.74 - 34.42 (28.95)	24.74 - 41.09 (34.27)
2025	30.96 - 41.09 (37.79)	24.74 - 34.42 (28.95)	24.74 - 41.09 (34.32)

The remaining tables in this section present equivalent information for the other regulatory alternatives. For each regulatory alternative, the first table presents the alternative as actually examined by the agency, and the second table presents the underlying alternative absent adjustments for improvements to automotive air conditioner efficiency for the reader's easier comparison to the CAFE increases analyzed in the MY 2012-2016 rulemaking. As above, for each fleet and model year, the fuel economy targets specified by the target curve are presented as a range, and the estimated average required fuel economy is presented in parentheses (and subject to uncertainty and change related to uncertainty in the agency's market forecast).

The "preferred alternative" represents the rates of increase which the agency has tentatively concluded are maximum feasible under EPCA/EISA for passenger cars and light trucks manufactured in MYs 2017-2025. Section B.2 below discusses why the agency has tentatively concluded that the preferred alternative standards are maximum feasible.

Table III.B.1-4. Preferred Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.65 - 43.61 (39.97)	25.09 - 36.26 (29.41)	25.09 - 43.61 (35.30)
2018	33.84 - 45.21 (41.44)	25.20 - 37.36 (30.04)	25.20 - 45.21 (36.41)
2019	35.07 - 46.87 (43.00)	25.25 - 38.16 (30.57)	25.25 - 46.87 (37.53)
2020	36.47 - 48.74 (44.66)	25.25 - 39.11 (31.21)	25.25 - 48.74 (38.77)
2021	38.02 - 50.83 (46.61)	25.25 - 41.80 (33.34)	25.25 - 50.83 (40.90)
2022	39.79 - 53.21 (48.80)	26.29 - 43.79 (34.92)	26.29 - 53.21 (42.88)
2023	41.64 - 55.71 (51.05)	27.53 - 45.89 (36.65)	27.53 - 55.71 (45.01)
2024	43.58 - 58.32 (53.46)	28.83 - 48.09 (38.47)	28.83 - 58.32 (47.29)
2025	45.61 - 61.07 (55.96)	30.19 - 50.39 (40.33)	30.19 - 61.07 (49.60)

Table III.B.1-5. Preferred Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.06 - 42.57 (39.10)	24.74 - 35.53 (28.95)	24.74 - 42.57 (34.63)
2018	33.21 - 44.09 (40.51)	24.74 - 36.37 (29.41)	24.74 - 44.09 (35.62)
2019	34.39 - 45.66 (41.95)	24.74 - 37.01 (29.85)	24.74 - 45.66 (36.63)
2020	35.73 - 47.44 (43.59)	24.74 - 37.91 (30.44)	24.74 - 47.44 (37.83)
2021	37.22 - 49.42 (45.39)	24.74 - 40.43 (32.47)	24.74 - 49.42 (39.83)
2022	38.92 - 51.66 (47.48)	25.74 - 42.29 (33.95)	25.74 - 51.66 (41.71)
2023	40.69 - 54.01 (49.63)	26.93 - 44.24 (35.57)	26.93 - 54.01 (43.73)
2024	42.54 - 56.47 (51.90)	28.17 - 46.28 (37.30)	28.17 - 56.47 (45.88)
2025	44.47 - 59.04 (54.26)	29.47 - 48.42 (39.03)	29.47 - 59.04 (48.05)

NHTSA also considered alternatives under which the mathematical functions (*i.e.*, curves) defining fuel economy targets were advanced in stringency at constant annual rates ranging from 2% to 7%, which we believed represented a reasonable range of possible alternative ways the agency could balance the required statutory factors to determine the maximum feasible levels of improvement in fuel economy that manufacturers could achieve during MYs 2017-2025. Because NHTSA developed these curves mathematically (*i.e.*, calculating the gpm-based coefficients defining a given model year's curve by multiplying the coefficients applicable to the prior model year by one minus the rate of increase), yet average required fuel economy levels depend also on fleet composition, the resultant average required fuel economy levels do not progress at precisely the same rates of increase as do the underlying mathematical functions – that is, a reader will not be able to calculate the same fuel economy levels by multiplying the initial mpg number times 1.03, 1.04, etc., as the agency calculates based on multiplying the curve coefficients. While NHTSA recognizes that alternatives based on multiplying mpg levels may be easier for some readers to understand, we considered alternatives in terms of multiplying curve coefficients instead because it is the actual target curves that are the standards with which industry has to comply, and not the estimated mpg levels that result from those target curves in the agency's analysis.

Characteristics of these alternatives are summarized in the twelve tables. The agency analyzed each alternative with and without AC adjustments, and as above, each alternative is presented below with and without AC adjustments for the reader's reference:

Table III.B.1-1. 2% Annual Increase Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.16 - 42.95 (39.38)	25.09 - 37.52 (30.12)	25.09 - 42.95 (35.37)
2018	32.83 - 43.85 (40.21)	25.20 - 38.55 (30.80)	25.20 - 43.85 (36.19)
2019	33.51 - 44.76 (41.05)	25.25 - 39.48 (31.56)	25.25 - 44.76 (37.06)
2020	34.21 - 45.70 (41.90)	25.25 - 40.32 (32.15)	25.25 - 45.70 (37.85)
2021	34.92 - 46.66 (42.79)	25.25 - 41.17 (32.83)	25.25 - 46.66 (38.67)
2022	35.65 - 47.64 (43.70)	25.25 - 42.03 (33.55)	25.25 - 47.64 (39.55)
2023	36.39 - 48.63 (44.59)	25.77 - 42.92 (34.27)	25.77 - 48.63 (40.43)
2024	37.15 - 49.65 (45.54)	26.31 - 43.83 (35.08)	26.31 - 49.65 (41.41)
2025	37.92 - 50.70 (46.49)	26.86 - 44.76 (35.84)	26.86 - 50.70 (42.32)

Table III.B.1-2. 2% Annual Increase Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	31.59 - 41.94 (38.53)	24.74 - 36.74 (29.60)	24.74 - 41.94 (34.68)
2018	32.23 - 42.79 (39.33)	24.74 - 37.49 (30.13)	24.74 - 42.79 (35.39)
2019	32.89 - 43.66 (40.13)	24.74 - 38.26 (30.76)	24.74 - 43.66 (36.18)
2020	33.56 - 44.56 (40.94)	24.74 - 39.04 (31.31)	24.74 - 44.56 (36.94)
2021	34.25 - 45.46 (41.78)	24.74 - 39.84 (31.98)	24.74 - 45.46 (37.72)
2022	34.95 - 46.39 (42.63)	24.74 - 40.65 (32.64)	24.74 - 46.39 (38.54)
2023	35.66 - 47.34 (43.51)	25.25 - 41.48 (33.37)	25.25 - 47.34 (39.42)
2024	36.39 - 48.31 (44.40)	25.76 - 42.33 (34.11)	25.76 - 48.31 (40.32)
2025	37.13 - 49.29 (45.30)	26.29 - 43.19 (34.84)	26.29 - 49.29 (41.21)

Table III.B.1-8. 3% Annual Increase Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.50 - 43.40 (39.81)	25.09 - 37.92 (30.36)	25.09 - 43.40 (35.72)
2018	33.52 - 44.78 (41.06)	25.20 - 39.37 (31.46)	25.20 - 44.78 (36.95)
2019	34.58 - 46.20 (42.37)	25.25 - 40.76 (32.56)	25.25 - 46.20 (38.24)
2020	35.67 - 47.67 (43.68)	25.26 - 42.06 (33.51)	25.26 - 47.67 (39.46)
2021	36.79 - 49.18 (45.09)	26.06 - 43.41 (34.60)	26.06 - 49.18 (40.75)
2022	37.96 - 50.75 (46.54)	26.88 - 44.80 (35.71)	26.88 - 50.75 (42.11)
2023	39.16 - 52.36 (47.98)	27.73 - 46.24 (36.90)	27.73 - 52.36 (43.51)
2024	40.40 - 54.03 (49.51)	28.61 - 47.72 (38.17)	28.61 - 54.03 (45.03)
2025	41.67 - 55.75 (51.12)	29.52 - 49.26 (39.40)	29.52 - 55.75 (46.54)

Table III.B.1-9. 3% Annual Increase Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	31.91 - 42.37 (38.91)	24.74 - 37.12 (29.87)	24.74 - 42.37 (35.01)
2018	32.90 - 43.68 (40.13)	24.74 - 38.27 (30.73)	24.74 - 43.68 (36.11)
2019	33.92 - 45.03 (41.38)	24.74 - 39.46 (31.69)	24.74 - 45.03 (37.29)
2020	34.97 - 46.42 (42.62)	24.76 - 40.68 (32.63)	24.76 - 46.42 (38.47)
2021	36.05 - 47.86 (43.98)	25.52 - 41.93 (33.66)	25.52 - 47.86 (39.70)
2022	37.16 - 49.34 (45.37)	26.31 - 43.23 (34.71)	26.31 - 49.34 (41.00)
2023	38.31 - 50.86 (46.73)	27.13 - 44.57 (35.84)	27.13 - 50.86 (42.34)
2024	39.50 - 52.44 (48.19)	27.96 - 45.95 (37.04)	27.96 - 52.44 (43.78)
2025	40.72 - 54.06 (49.69)	28.83 - 47.37 (38.20)	28.83 - 54.06 (45.19)

Table III.B.1-10. 4% Annual Increase Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.84 - 43.87 (40.22)	25.09 - 38.32 (30.64)	25.09 - 43.87 (36.07)
2018	34.24 - 45.74 (41.94)	25.20 - 40.22 (32.10)	25.20 - 45.74 (37.73)
2019	35.69 - 47.70 (43.73)	25.28 - 42.09 (33.57)	25.28 - 47.70 (39.45)
2020	37.21 - 49.74 (45.57)	26.36 - 43.91 (34.98)	26.36 - 49.74 (41.18)
2021	38.79 - 51.87 (47.54)	27.48 - 45.80 (36.49)	27.48 - 51.87 (42.97)
2022	40.45 - 54.10 (49.61)	28.65 - 47.78 (38.07)	28.65 - 54.10 (44.89)
2023	42.17 - 56.43 (51.72)	29.87 - 49.86 (39.79)	29.87 - 56.43 (46.91)
2024	43.97 - 58.85 (53.94)	31.15 - 52.02 (41.58)	31.15 - 58.85 (49.06)
2025	45.85 - 61.39 (56.27)	32.48 - 54.28 (43.41)	32.48 - 61.39 (51.25)

Table III.B.1-11. 4% Annual Increase Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.25 - 42.81 (39.32)	24.74 - 37.51 (30.14)	24.74 - 42.81 (35.36)
2018	33.59 - 44.59 (40.97)	24.74 - 39.07 (31.35)	24.74 - 44.59 (36.85)
2019	34.99 - 46.45 (42.69)	24.77 - 40.70 (32.69)	24.77 - 46.45 (38.47)
2020	36.45 - 48.39 (44.45)	25.80 - 42.40 (34.00)	25.80 - 48.39 (40.11)
2021	37.97 - 50.40 (46.33)	26.88 - 44.16 (35.44)	26.88 - 50.40 (41.82)
2022	39.55 - 52.50 (48.25)	28.00 - 46.00 (36.94)	28.00 - 52.50 (43.62)
2023	41.20 - 54.69 (50.25)	29.17 - 47.92 (38.52)	29.17 - 54.69 (45.52)
2024	42.91 - 56.97 (52.35)	30.38 - 49.92 (40.21)	30.38 - 56.97 (47.54)
2025	44.70 - 59.34 (54.54)	31.65 - 52.00 (41.95)	31.65 - 59.34 (49.61)

Table III.B.1-12. 5% Annual Increase Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	33.19 - 44.34 (40.64)	25.09 - 38.73 (30.93)	25.09 - 44.34 (36.43)
2018	34.98 - 46.73 (42.84)	25.20 - 41.10 (32.79)	25.20 - 46.73 (38.54)
2019	36.85 - 49.26 (45.17)	26.10 - 43.48 (34.68)	26.10 - 49.26 (40.75)
2020	38.84 - 51.93 (47.60)	27.51 - 45.85 (36.47)	27.51 - 51.93 (42.98)
2021	40.93 - 54.75 (50.20)	28.99 - 48.36 (38.49)	28.99 - 54.75 (45.35)
2022	43.13 - 57.72 (52.90)	30.55 - 51.01 (40.61)	30.55 - 57.72 (47.87)
2023	45.46 - 60.86 (55.75)	32.20 - 53.81 (42.90)	32.20 - 60.86 (50.58)
2024	47.92 - 64.18 (58.82)	33.94 - 56.78 (45.37)	33.94 - 64.18 (53.50)
2025	50.51 - 67.69 (62.03)	35.78 - 59.91 (47.86)	35.78 - 67.69 (56.49)

Table III.B.1-13. 5% Annual Increase Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.59 - 43.26 (39.74)	24.74 - 37.91 (30.41)	24.74 - 43.26 (35.70)
2018	34.30 - 45.54 (41.84)	24.74 - 39.90 (32.02)	24.74 - 45.54 (37.64)
2019	36.11 - 47.93 (44.05)	25.56 - 42.00 (33.75)	25.56 - 47.93 (39.70)
2020	38.01 - 50.46 (46.36)	26.91 - 44.21 (35.45)	26.91 - 50.46 (41.82)
2021	40.01 - 53.11 (48.81)	28.32 - 46.54 (37.33)	28.32 - 53.11 (44.05)
2022	42.11 - 55.91 (51.40)	29.82 - 48.99 (39.35)	29.82 - 55.91 (46.46)
2023	44.33 - 58.85 (54.07)	31.38 - 51.57 (41.45)	31.38 - 58.85 (48.98)
2024	46.66 - 61.95 (56.95)	33.04 - 54.28 (43.74)	33.04 - 61.95 (51.71)
2025	49.12 - 65.21 (59.92)	34.77 - 57.14 (46.07)	34.77 - 65.21 (54.50)

Table III.B.1-14. 6% Annual Increase Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	33.55 - 44.82 (41.10)	25.09 - 39.15 (31.27)	25.09 - 44.82 (36.84)
2018	35.74 - 47.76 (43.79)	25.26 - 42.01 (33.48)	25.26 - 47.76 (39.38)
2019	38.07 - 50.90 (46.67)	26.96 - 44.93 (35.82)	26.96 - 50.90 (42.10)
2020	40.55 - 54.24 (49.69)	28.72 - 47.91 (38.13)	28.72 - 54.24 (44.89)
2021	43.21 - 57.82 (52.99)	30.60 - 51.10 (40.67)	30.60 - 57.82 (47.90)
2022	46.03 - 61.64 (56.49)	32.61 - 54.50 (43.40)	32.61 - 61.64 (51.14)
2023	49.05 - 65.72 (60.20)	34.75 - 58.15 (46.33)	34.75 - 65.72 (54.62)
2024	52.28 - 70.08 (64.21)	37.03 - 62.04 (49.55)	37.03 - 70.08 (58.42)
2025	55.72 - 74.74 (68.46)	39.47 - 66.22 (52.84)	39.47 - 74.74 (62.36)

Table III.B.1-15. 6% Annual Increase Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	32.93 - 43.72 (40.16)	24.74 - 38.31 (30.71)	24.74 - 43.72 (36.07)
2018	35.03 - 46.51 (42.73)	24.80 - 40.75 (32.68)	24.80 - 46.51 (38.43)
2019	37.27 - 49.48 (45.48)	26.39 - 43.35 (34.84)	26.39 - 49.48 (40.99)
2020	39.65 - 52.64 (48.34)	28.07 - 46.12 (36.95)	28.07 - 52.64 (43.60)
2021	42.18 - 56.00 (51.44)	29.86 - 49.07 (39.37)	29.86 - 56.00 (46.44)
2022	44.87 - 59.57 (54.77)	31.77 - 52.20 (41.91)	31.77 - 59.57 (49.50)
2023	47.74 - 63.37 (58.24)	33.80 - 55.53 (44.65)	33.80 - 63.37 (52.76)
2024	50.78 - 67.42 (61.96)	35.95 - 59.07 (47.60)	35.95 - 67.42 (56.27)
2025	54.03 - 71.72 (65.91)	38.25 - 62.85 (50.68)	38.25 - 71.72 (59.95)

Table III.B.1-16. 7% Annual Increase Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	33.92 - 45.32 (41.55)	25.09 - 39.58 (31.59)	25.09 - 45.32 (37.22)
2018	36.53 - 48.82 (44.77)	25.82 - 42.94 (34.23)	25.82 - 48.82 (40.26)
2019	39.34 - 52.60 (48.22)	27.86 - 46.45 (37.05)	27.86 - 52.60 (43.52)
2020	42.37 - 56.69 (51.93)	30.01 - 50.09 (39.82)	30.01 - 56.69 (46.90)
2021	45.64 - 61.10 (55.98)	32.33 - 54.03 (43.00)	32.33 - 61.10 (50.62)
2022	49.17 - 65.87 (60.37)	34.83 - 58.29 (46.35)	34.83 - 65.87 (54.64)
2023	52.98 - 71.03 (65.06)	37.53 - 62.90 (50.09)	37.53 - 71.03 (59.04)
2024	57.10 - 76.61 (70.15)	40.45 - 67.89 (54.16)	40.45 - 76.61 (63.84)
2025	61.54 - 82.64 (75.68)	43.60 - 73.30 (58.44)	43.60 - 82.64 (68.95)

Table III.B.1-17. 7% Annual Increase Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	33.29 - 44.19 (40.62)	24.74 - 38.72 (31.02)	24.74 - 44.19 (36.47)
2018	35.79 - 47.52 (43.65)	25.34 - 41.63 (33.39)	25.34 - 47.52 (39.26)
2019	38.49 - 51.09 (46.96)	27.25 - 44.77 (35.96)	27.25 - 51.09 (42.32)
2020	41.38 - 54.94 (50.46)	29.30 - 48.14 (38.60)	29.30 - 54.94 (45.53)
2021	44.50 - 59.07 (54.28)	31.50 - 51.76 (41.55)	31.50 - 59.07 (49.01)
2022	47.85 - 63.52 (58.39)	33.87 - 55.66 (44.70)	33.87 - 63.52 (52.78)
2023	51.45 - 68.30 (62.75)	36.42 - 59.85 (48.13)	36.42 - 68.30 (56.85)
2024	55.32 - 73.44 (67.51)	39.17 - 64.35 (51.86)	39.17 - 73.44 (61.31)
2025	59.48 - 78.97 (72.59)	42.11 - 69.20 (55.81)	42.11 - 78.97 (66.02)

NHTSA also considered a regulatory alternative under which the stringency in each model year was set at a level estimated to maximize net benefits. Executive Order 12866 states that in choosing among regulatory alternatives in rulemakings, agencies should select the approach that maximizes net benefits (including potential economic, environmental, public health and safety, and other advantages; distributive impacts; and equity), unless a statute requires another approach. Executive Order 13563, signed by President Obama on January 18, 2011, reiterates that agencies should focus on approaches that maximize net benefits, to the extent consistent with applicable law.

In the context of CAFE rulemakings, NHTSA has long considered regulatory alternatives that approximate the levels at which net benefits are maximized. Because EPCA/EISA requires that CAFE standards be set separately for cars and trucks in each model year, finding the precise level at which net benefits are maximized for each fleet, for each year, taking into account all of the considerations enumerated by EOs 12866 and 13563, is challenging to say the least. While NHTSA accounts for many costs and benefits associated with setting CAFE standards through its modeling analysis, we are careful to emphasize that the modeling analysis does not, and indeed, cannot capture all possible impacts – some impacts, such as lifecycle maintenance and repair costs, for example, are currently too uncertain to quantify and include in the analysis. That uncertainty affects our ability to determine the absolute single level of stringency for each fleet, for each model year, which reflects perfect maximization of net benefits.

We have, nevertheless, done our best over multiple rulemakings to approximate in our modeling analysis a regulatory alternative that maximizes net benefits. In the rulemaking to establish the MY 2011 standards for cars and trucks, for example, NHTSA used the CAFE model to test a wide range of potential stringencies for cars and trucks separately, calculating the net benefits (*i.e.,* social benefits of standards minus total costs of standards) at each stringency, and then identifying the stringency that yielded the highest level of net benefits for that fleet, for that single model year and using that as the regulatory alternative that maximized net benefits.

Because the CAFE model has evolved since that rulemaking, the agency's ability to use it to determine the regulatory alternative that maximizes net benefits has also had to evolve. As the CAFE model exists today, it includes the ability to simulate multiyear planning effects—that is, the potential that a manufacturer might apply "extra" technology in earlier model years if doing so would facilitate compliance with standards in later model years. As discussed below, consideration of these effects reveals interdependencies the net benefit maximizing stringencies in different model years.

Thus, for this rulemaking, as for the MYs 2012-2016 rulemaking, the maximum net benefit and "total cost = total benefit" regulatory alternatives were developed using the CAFE model to perform corresponding optimizations on a year-by-year basis. For example, when estimating stringencies at which net benefits are maximized, the model begins by examining MY 2017, seeking the car and truck stringencies that would maximize net benefits in MY 2017, without any information regarding post-MY 2017 standards. The model then performs a compliance simulation for MY 2017; carries resultant technology forward into MY 2018; seeks car and truck stringencies that would maximize net benefits in MY 2018; and continues the sequence through MY 2025. However, once standards throughout MYs 2017-2025 are "known" at the end of that sequence, the compliance simulation in earlier model years is revisited and influenced by standards in later model years. For example, the model might add "extra" technology in MY 2015 to facilitate compliance with expected MY 2019 standards, and carry that technology forward to MY 2016 and MY 2017. This extra carried-forward technology could increase the net benefits attributed to the MY 2017 standards that had previously been estimated to maximize net benefits, *absent information regarding post-MY 2017* *standards*. As a result, standards estimated to maximize net benefits on a year-by-year basis do not necessarily produce maximum net benefits—in any specific model year or over a series of model years—when standards in all model years are defined.[55] Given economic and technology-related inputs to the agency's analysis, opportunities to add fuel-saving technologies are sometimes "exhausted" before total costs reach the level of total benefits; when this occurs in a given model year, this regulatory alternative is defined by the stringency leading to this exhaustion of available technology. We believe, nevertheless, that this is an appropriate approach given that manufacturers seeking to comply with CAFE standards do not consider each model year in isolation, but rather within the context of a product plans spanning multiple model years—in other words, manufacturers engage in multiyear planning. For example, if a manufacturer is redesigning a vehicle model in MY 2012, and does not plan to redesign the vehicle again until MY 2019, the manufacturer is likely to consider what standards will be in place between MY 2012 and MY 2019, and factor that information into decisions about what technologies to apply to that vehicle. Insofar as manufacturers actually engage in such planning, the costs and benefits of new standards over time will be affected, and the net benefit maximizing stringencies will also be affected.

Table III.B.1-18. Maximum Net Benefit Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	35.60 - 47.64 (43.64)	25.67 - 42.60 (33.98)	25.67 - 47.64 (39.50)
2018	37.27 - 49.86 (45.69)	27.02 - 44.93 (35.84)	27.02 - 49.86 (41.54)
2019	38.31 - 51.13 (46.91)	28.65 - 47.78 (38.10)	28.65 - 51.13 (43.32)
2020	39.25 - 52.51 (48.11)	29.70 - 49.62 (39.41)	29.70 - 52.51 (44.64)
2021	39.67 - 53.04 (48.61)	30.64 - 51.13 (40.71)	30.64 - 53.04 (45.51)
2022	39.87 - 53.35 (48.90)	31.27 - 52.22 (41.57)	31.27 - 53.35 (46.08)
2023	40.29 - 53.89 (49.37)	32.11 - 53.63 (42.74)	32.11 - 53.89 (46.89)
2024	41.13 - 54.95 (50.40)	33.27 - 55.60 (44.42)	33.27 - 55.60 (48.23)
2025	41.76 - 55.90 (51.22)	34.12 - 57.13 (45.61)	34.12 - 57.13 (49.22)

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[55] As a potential means to address these interactions between model years when standards are defined and multiyear planning effects are simulated, Volpe Center staff have experimented with techniques to optimize a steady rate of increase. Under this approach, when a given level of stringency in MY 2017 is tested, the post-MY 2017 standards are also defined, because they are set at levels reflecting a constant rate of increase in stringency. However, EISA's requirement that the standards be set at the maximum feasible levels in each specific model year precludes the presumption that the stringency of standards would increase at a constant rate. On the other hand, testing a wide range of both profiles and levels of increases over nine model years poses a technical challenge the agency has not determined how best to address for purposes of maximizing net benefits. In the agency's judgment, further conceptual work may be required regarding the maximization of net benefits in each model year when net benefits in any given model year depend on the stringency of standards in earlier and later model years.

Table III.B.1-19. Maximum Net Benefit Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	34.90 - 46.40 (42.58)	25.30 - 41.60 (33.35)	25.30 - 46.40 (38.64)
2018	36.50 - 48.50 (44.58)	26.50 - 43.50 (34.91)	26.50 - 48.50 (40.49)
2019	37.50 - 49.70 (45.70)	28.00 - 46.00 (36.94)	28.00 - 49.70 (42.12)
2020	38.40 - 51.00 (46.86)	29.00 - 47.70 (38.19)	29.00 - 51.00 (43.38)
2021	38.80 - 51.50 (47.33)	29.90 - 49.10 (39.40)	29.90 - 51.50 (44.21)
2022	39.00 - 51.80 (47.58)	30.50 - 50.10 (40.21)	30.50 - 51.80 (44.74)
2023	39.40 - 52.30 (48.05)	31.30 - 51.40 (41.33)	31.30 - 52.30 (45.52)
2024	40.20 - 53.30 (49.04)	32.40 - 53.20 (42.89)	32.40 - 53.30 (46.79)
2025	40.80 - 54.20 (49.78)	33.20 - 54.60 (44.02)	33.20 - 54.60 (47.72)

Finally, and as mentioned above, NHTSA considered a regulatory alternative under which the stringency in each model year was set at a level estimated to produce incremental costs most closely equal to incremental benefits. The agency also used the CAFE model to progressively estimate stringencies defining this "Total Cost = Total Benefit" or "Zero Net Benefit" alternative.[56] As above, when technologies are exhausted before total costs reach the level of total benefits, this regulatory alternative is defined by the stringency leading to this exhaustion of available technology.

Table III.B.1-20. Total Cost = Total Benefit Alternative

Model Year	Passenger Cars	Light Trucks	Fleet
2017	36.54 - 48.80 (44.78)	25.87 - 42.81 (34.16)	25.87 - 48.80 (40.18)
2018	38.10 - 50.92 (46.67)	27.13 - 45.25 (36.01)	27.13 - 50.92 (42.13)
2019	39.25 - 52.51 (48.12)	28.55 - 47.56 (37.90)	28.55 - 52.51 (43.88)
2020	40.50 - 54.10 (49.60)	29.80 - 49.83 (39.61)	29.80 - 54.10 (45.55)
2021	41.34 - 55.27 (50.66)	30.64 - 51.13 (40.71)	30.64 - 55.27 (46.65)
2022	43.23 - 57.93 (53.09)	31.06 - 52.00 (41.34)	31.06 - 57.93 (48.32)
2023	44.91 - 60.06 (55.01)	32.75 - 54.72 (43.61)	32.75 - 60.06 (50.50)
2024	46.48 - 62.31 (57.07)	34.12 - 57.13 (45.59)	34.12 - 62.31 (52.63)
2025	47.96 - 64.24 (58.88)	35.17 - 58.88 (47.07)	35.17 - 64.24 (54.36)

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[56] The optimization procedures used to develop this regulatory alternative are also subject to the uncertainties and inter-MY dependencies discussed in the preceding footnote.

Table III.B.1-21. Total Cost = Total Benefit Alternative before Application of AC Adjustments

Model Year	Passenger Cars	Light Trucks	Fleet
2017	35.80 - 47.50 (43.67)	25.50 - 41.80 (33.50)	25.50 - 47.50 (39.28)
2018	37.30 - 49.50 (45.48)	26.60 - 43.80 (35.09)	26.60 - 49.50 (41.05)
2019	38.40 - 51.00 (46.86)	27.90 - 45.80 (36.78)	27.90 - 51.00 (42.67)
2020	39.60 - 52.50 (48.25)	29.10 - 47.90 (38.38)	29.10 - 52.50 (44.24)
2021	40.40 - 53.60 (49.28)	29.90 - 49.10 (39.40)	29.90 - 53.60 (45.30)
2022	42.20 - 56.10 (51.54)	30.30 - 49.90 (40.00)	30.30 - 56.10 (46.85)
2023	43.80 - 58.10 (53.37)	31.90 - 52.40 (42.16)	31.90 - 58.10 (48.93)
2024	45.30 - 60.20 (55.29)	33.20 - 54.60 (43.96)	33.20 - 60.20 (50.89)
2025	46.70 - 62.00 (57.00)	34.20 - 56.20 (45.33)	34.20 - 62.00 (52.52)

2. Why is NHTSA proposing the Preferred Alternative?

NHTSA has tentatively concluded that the standards presented above in Section IV.E are the maximum feasible standards for passenger cars and light trucks in MYs 2017-2025. EPCA/EISA requires NHTSA to consider four statutory factors in determining the maximum feasible CAFE standards in a rulemaking: specifically, technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the nation to conserve energy. The agency considered a number of regulatory alternatives in its analysis of potential CAFE standards for those model years, including several that increase stringency on average at set percentages each year, one that approximates the point at which net benefits are maximized in each model year, and one that approximates the point at which total costs equal total benefits in each model year. Some of those alternatives represent standards that would be more stringent than the proposed standards,[57] and some are less stringent.[58] As the discussion below explains, we tentatively conclude that the correct balancing of the relevant factors that the agency must consider in determining the maximum feasible standards recognizes economic practicability concerns as discussed below, and sets standards accordingly. We expect that the proposed standards will enable further research and development into the more advanced fuel economy-improving technologies, and enable significant fuel savings and environmental benefits throughout the program, with particularly substantial benefits in the later years of the program and beyond. Additionally, consistent with Executive Order 13563, the agency believes that the benefits of the preferred alternative amply justify the costs; indeed, the monetized benefits exceed the monetized costs by $358 billion over the lifetime of the vehicles

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[57] We recognize that higher standards would help the need of the nation to conserve more energy and might potentially be technologically feasible (in the narrowest sense) during those model years, but based on our analysis and the evidence presented by the industry, we tentatively conclude that higher standards would not represent the proper balancing for MYs 2017-2025 cars and trucks.

[58] We also recognize that lower standards might be less burdensome on the industry, but considering the environmental impacts of the different regulatory alternatives as required under NEPA and the need of the nation to conserve energy, we do not believe they would have represented the appropriate balancing of the relevant factors, because they would have left technology, fuel savings, and emissions reductions on the table unnecessarily, and not contributed as much as possible to reducing our nation's energy security and climate change concerns.

covered by the proposed standards. In full consideration of all of the information currently before the agency, we have weighed the statutory factors carefully and selected proposed passenger car and light truck standards that we believe are the maximum feasible for MYs 2017-2025.

a. What are NHTSA's statutory obligations?

As discussed above in Section IV.D, NHTSA sets CAFE standards under EPCA, as amended by EISA, and is also subject to the APA and NEPA in developing and promulgating CAFE standards.

NEPA requires the agency to develop and consider the findings of an Environmental Impact Statement (EIS) for "major Federal actions significantly affecting the quality of the human environment." NHTSA has determined that this action is such an action and therefore that an EIS is necessary, and has accordingly prepared a Draft EIS to inform its development and consideration of the proposed standards. The agency has evaluated the environmental impacts of a range of regulatory alternatives in our proposal, and integrated the results of that consideration into our balancing of the EPCA/EISA factors, as discussed below.

The APA and relevant case law requires our rulemaking decision to be rational, based on consideration of the relevant factors, and within the scope of the authority delegated to the agency by EPCA/EISA. The relevant factors are those required by EPCA/EISA and the additional factors approved in case law as ones historically considered by the agency in determining the maximum feasible CAFE standards, such as safety. The statute requires us to set standards at the maximum feasible level for passenger cars and light trucks for each model year, and the agency tentatively concludes that the standards, if adopted as proposed, would satisfy this requirement. NHTSA has carefully examined the relevant data and other considerations, as discussed below in our explanation of our tentative conclusion that the proposed standards are the maximum feasible levels for those model years based on our evaluation of the information before us for this NPRM.

As discussed in Section IV.D, EPCA/EISA requires that NHTSA establish separate passenger car and light truck standards at "the maximum feasible average fuel economy level that it decides the manufacturers can achieve in that model year," based on the agency's consideration of four statutory factors: technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the nation to conserve energy.[59] NHTSA has developed definitions for these

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[59] As explained in Section IV.D, EPCA also provides that in determining the level at which it should set CAFE standards for a particular model year, NHTSA may not consider the ability of manufacturers to take advantage of several statutory provisions that facilitate compliance with the CAFE standards and thereby reduce the costs of compliance. Specifically, in determining the maximum feasible level of fuel economy for passenger cars and light trucks, NHTSA cannot consider the fuel economy benefits of "dedicated" alternative fuel vehicles (like battery electric vehicles or natural gas vehicles), must consider dual-fueled automobiles to be operated only on gasoline or diesel fuel (at least through MY 2019), and may not consider the ability of manufacturers to use, trade, or transfer credits. This provision limits, to some extent, the fuel economy levels that NHTSA can find to be "maximum feasible" – if NHTSA cannot consider the

terms over the course of multiple CAFE rulemakings[60] and determines the appropriate weight and balancing of the terms given the circumstances in each CAFE rulemaking. For MYs 2011–2020, EPCA further requires that separate standards for passenger cars and for light trucks be set at levels high enough to ensure that the CAFE of the industry-wide combined fleet of new passenger cars and light trucks reaches at least 35 mpg not later than MY 2020. For model years after 2020, standards need simply be set at the maximum feasible level.

The agency thus balances the relevant factors to determine the maximum feasible level of the CAFE standards for each fleet, in each model year. The next section discusses how the agency balanced the factors for this proposal, and why we believe the proposed standards are the maximum feasible.

b. How did the agency balance the factors for this NPRM?

There are numerous ways that the relevant factors can be balanced (and thus weight given to each factor) depending on the agency's policy priorities and on the information before the agency regarding any given model year, and the agency therefore considered a range of alternatives that represent different regulatory options that we thought were potentially reasonable for purposes of this rulemaking. For this proposal, the regulatory alternatives considered in the agency's analysis include several alternatives for fuel economy levels that increase annually, on average, at set rates – specifically, 2 %/year, 3 %/year, 4 %/year, 5 %/year, 6 %/year, and 7 %/year.[61] Analysis of these various rates of increase effectively encompasses the entire range of fuel economy improvements that, based on information currently available to the agency, could conceivably fall within the statutory boundary of "maximum feasible" standards. The regulatory alternatives also include two alternatives based on benefit-cost criteria, one in which standards would be set at the point where net benefits would be maximized for each fleet in each year (MNB), and another in which standards would be set at the point at which total costs would be most nearly equal to total benefits for each fleet in each year (TC=TB),[62] as well as the preferred alternative, which is within the range of the other alternatives. Because the

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fuel economy of electric vehicles, for example, NHTSA cannot set standards predicated on manufacturers' usage of electric vehicles to meet the standards.

[60] These factors are defined in Section IV.D; for brevity, we do not repeat those definitions here.

[61] This is an approach similar to that used by the agency in the MY 2012-2016 rulemaking, in which we also considered several alternatives that increased annually, on average, at 3%, 4 %, 5 %, 6 % and 7 %/year. The "percent-per-year" alternatives in this proposal are somewhat different from those considered in the MY 2012-2016 rulemaking, however, in terms of how the annual rate of increase is applied. For this proposal, the stringency curves are themselves advanced directly by the annual increase amount, without reference to any yearly changes in the fleet mix. In the 2012-2016 rule, the annual increases for the stringency alternatives reflected the estimated required fuel economy of the fleet which accounted for both the changes in the target curves and changes in the fleet mix.

[62] We included the MNB and TC=TB alternatives in part for the reference of commenters familiar with NHTSA's past several CAFE rulemakings – these alternatives represent balancings carefully considered by the agency in past rulemaking actions as potentially maximum feasible – and because Executive Orders 12866 and 13563 focus attention on an approach that maximizes net benefits. The assessment of maximum net benefits is challenging in the context of setting CAFE standards, in part because standards which maximize net benefits for each fleet, for each model year, would not necessarily be the standards that lead to the greatest net benefits over the entire rulemaking period

agency could conceivably select any of the regulatory alternatives above, all of which fall between 2 %/year and 7 %/year, inclusive, the Draft EIS that accompanies this proposal analyzes these lower and upper bounds as well as the preferred alternative. Additionally, the Draft EIS analyzes a "No Action Alternative," which assumes that, for MYs 2017 and beyond, NHTSA would set standards at the same level as MY 2016. The No Action Alternative provides a baseline for comparing the environmental impacts of the other alternatives.

NHTSA believes that this approach clearly communicates the level of stringency of each alternative and allows us to identify alternatives that represent different ways to balance NHTSA's statutory factors under EPCA/EISA. Each of the listed alternatives represents, in part, a different way in which NHTSA could conceivably balance different policies and considerations in setting the standards that achieve the maximum feasible levels. For example, the 2% Alternative, the least stringent alternative, would represent a balancing in which economic practicability – which include concerns about availability of technology, capital, and consumer preferences for vehicles built to meet the future standards – weighs more heavily in the agency's consideration, and the need of the nation to conserve energy would weigh less heavily. In contrast, under the 7% Alternative, one of the most stringent, the need of the nation to conserve energy – which includes energy conservation and climate change considerations – would weigh more heavily in the agency's consideration, and other factors would weigh less heavily. Balancing and assessing the feasibility of different alternative can also be influenced by differences and uncertainties in the way in which key economic factors (*e.g.*, the price of fuel and the social cost of carbon) and technological inputs could be assessed and estimated or valued. While NHTSA believes that our analysis conducted in support of this NPRM uses the best and most transparent technology-related inputs and economic assumption inputs that the agencies could derive for MYs 2017-2025, we recognize that there is uncertainty in these inputs, and the balancing could be different if, for example, the inputs are adjusted in response to new information.

This is the first CAFE rulemaking in which the agency has looked this far into the future, which makes our traditional approach to balancing more challenging than in past (even recent past) rulemakings. NHTSA does not presently believe, for example, that technological feasibility as the agency defines it is as constraining in this rulemaking as it has been in the past in light of the time frame of this rulemaking. "Technological feasibility" refers to whether a particular method of improving fuel economy can be available for commercial application in the model year for which a standard is being established. In previous nearer-term CAFE rulemakings, it has been more difficult for the agency to say that the most advanced technologies would be available for commercial application in the model years for which standards were being established. For this rulemaking, which is longer term, NHTSA has considered all types of technologies that improve real-world fuel economy, including air-conditioner efficiency and other off-cycle technology, PHEVs, EVs, and highly-advanced internal combustion engines not yet in production, but all of which the agencies' expect to be commercially applicable by the rulemaking time frame. On the one hand, we recognize that some technologies that currently have limited commercial use cannot be deployed on every vehicle model in MY 2017, or even necessarily in MY 2025, but require a realistic schedule for widespread commercialization to be feasible. On the other hand, however, the agency expects, based on our analysis, that all of the alternatives could narrowly be considered as *technologically* feasible, in that they could be achieved based on the existence or projected future existence of technologies that could be incorporated on future vehicles, and enable any of the alternatives to be achieved on a technical basis alone if the level of resources that might be required practically to implement the technologies is not considered. If all alternatives are at least theoretically technologically feasible in the MY 2017-2025 timeframe, and the need of the nation is best served by pushing standards as stringent as possible, then the agency might be inclined to select the alternative that results in the very most stringent standards considered.

However, the agency must also consider what is required to practically implement technologies, which is part of economic practicability, and to which the most stringent alternatives give little weight. "Economic practicability" refers to whether a standard is one "within the financial capability of the industry, but not so stringent as to lead to adverse economic consequences, such as a significant loss of jobs or the unreasonable elimination of consumer choice." Consumer acceptability is also an element of economic practicability, one that is particularly difficult to gauge during times of uncertain fuel prices.[63] In a rulemaking such as the present one, determining economic practicability requires consideration of the uncertainty surrounding relatively distant future market conditions and consumer demand for fuel economy in addition to other vehicle attributes. In an attempt to evaluate the economic practicability of attribute-based standards, NHTSA includes a variety of factors in its analysis, including the annual rate at which manufacturers can increase the percentage of their fleet that employ a particular type of fuel-saving technology, the specific fleet mixes of different manufacturers, and assumptions about the cost of the standards to consumers and consumers' valuation of fuel economy, among other things. Ensuring that a reasonable amount of lead time exists to make capital investments and to devote the resources and time to design and prepare for commercial production of a more fuel efficient fleet is also relevant to the agency's consideration of economic practicability. Yet there are some aspects of economic practicability that the agency's analysis is not able to capture at this time – for example, the computer model that we use to analyze alternative standards does not account for all aspects of uncertainty, in part because the agency cannot know what we cannot know. The agency must thus account for uncertainty in the context of economic practicability as best as we can based on the entire record before us.

Both technological feasibility and economic practicability enter into the agency's determination of the maximum feasible levels of stringency, and economic practicability concerns may cause the agency to decide that standards that might be technologically feasible are, in fact, beyond maximum feasible. Standards that require aggressive application of and widespread deployment of advanced technologies could raise serious issues with the adequacy of time to coordinate such significant changes with manufacturers' redesign cycles, as well as with the availability of engineering resources

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[63] *See, e.g., Center for Auto Safety* v. *NHTSA (CAS)*, 793 F.2d 1322 (D.C. Cir. 1986) (Administrator's consideration of market demand as component of economic practicability found to be reasonable); *Public Citizen v. NHTSA*, 848 F.2d 256 (Congress established broad guidelines in the fuel economy statute; agency's decision to set lower standard was a reasonable accommodation of conflicting policies).

to develop and integrate the technologies into products, and the pace at which capital costs can be incurred to acquire and integrate the manufacturing and production equipment necessary to increase the production volume of the technologies. Moreover, the agency must consider whether consumers would be likely to accept a specific technological change under consideration, and how the cost to the consumer of making that change might affect their acceptance of it. The agency maintains, as it has in prior CAFE rulemakings, that there is an important distinction between considerations of technological feasibility and economic practicability. As explained above, a given level of performance may be technologically feasible (*i.e.*, setting aside economic constraints) for a given vehicle model. However, it would not be economically practicable to require a level of fleet average performance that assumes every vehicle will in the first year of the standards perform at the highest technologically feasible level, because manufacturers do not have unlimited access to the financial resources or may not practically be able to hire enough engineers, build enough facilities, and install enough tooling.

NHTSA therefore believes, based on the information currently before us, that economic practicability concerns render certain standards that might otherwise be technologically feasible to be beyond maximum feasible within the meaning of the statute for the 2017-2025 standards. Our analysis indicated that technologies seem to exist to meet the stringency levels required by future standards under nearly all of the regulatory alternatives; but it also indicated that manufacturers would not be able to apply those technologies quickly enough, given their redesign cycles, and the level of the resources that would be required to implement those technologies widely across their products, to meet all applicable standards in every model year under some of the alternatives.

Another consideration for economic practicability is incremental per-vehicle increases in technology cost. In looking at the incremental technology cost results from our modeling analysis, the agency saw that in progressing from alternatives with lower stringencies to alternatives with higher stringencies, technology cost increases (perhaps predictably) at a progressively higher rate, until the model projects that manufacturers are unable to comply with the increasing standards and enter (or deepen) non-compliance. Table III.B.2-1 and Table III.B.2 -2 show estimated cumulative lifetime fuel savings and estimated average vehicle cost increase for passenger cars and light trucks. The results show that there is a significant increase in technology cost between the 4% alternatives and the 5% alternatives.

TABLE III.B.2-1. ESTIMATED PASSENGER CAR CUMULATIVE LIFETIME FUEL SAVINGS AND AVERAGE VEHICLE COST INCREASE

	Cumulative Lifetime Fuel Savings 2017-2021 (billion gallons)	Average Vehicle Cost Increase in 2021 (2009 $)	Cumulative Lifetime Fuel Savings 2017-2025 (billion gallons)	Average Vehicle Cost Increase in 2025 (2009 $)
2%	22	$451	58	$684

3%	32	$775	85	$1,367
MNB	54	$1,060	108	$1,313
Preferred Alternative	39	$1,108	104	$2,023
4%	42	$1,252	110	$2,213
TC=TB	62	$1,607	135	$2,515
5%	51	$1,844	130	$3,040
6%	57	$1,789	140	$3,229
7%	61	$1,930	144	$3,304

TABLE III.B.2-2. ESTIMATED LIGHT TRUCK CUMULATIVE LIFETIME FUEL SAVINGS AND AVERAGE VEHICLE COST INCREASE

	Cumulative Lifetime Fuel Savings 2017-2021 (billion gallons)	Average Vehicle Cost Increase in 2021 (2009 $)	Cumulative Lifetime Fuel Savings 2017-2025 (billion gallons)	Average Vehicle Cost Increase in 2025 (2009 $)
2%	22	$498	53	$706
3%	33	$909	77	$1,308
Preferred Alternative	22	$965	69	$1,578
4%	41	$1,619	98	$2,423
MNB	62	$2,262	126	$3,427
TC=TB	62	$2,232	126	$3,416
5%	50	$2,154	116	$3,444
6%	56	$2,298	123	$3,611
7%	59	$2,482	127	$3,692

Thus, if technological feasibility and the need of the nation are not particularly limiting in a given rulemaking, then maximum feasible standards would be represented by the mpg levels that we could require of the industry to improve fuel economy before we reach a tipping point that presents risk of significantly adverse economic consequences. Standards that are lower than that point would likely not be maximum feasible, because such standards would leave fuel-saving technologies on the table unnecessarily; standards that are higher than that point would likely be beyond what the agency would consider economically practicable, and therefore beyond what we would consider maximum feasible, even if they might be technologically feasible or better meet the need of the nation to conserve energy. The agency does not believe that standards are balanced if they weight one or two factors so heavily as to ignore another.

We explained above that part of the way that we try to evaluate economic practicability is through a variety of model inputs, such as phase-in caps (the annual rate at which manufacturers can increase the percentage of their fleet that employ a particular type of fuel-saving technology) and redesign schedules to account for needed lead time. These inputs limit how much technology can be applied to a manufacturer's fleet in the agency's analysis attempting to simulate a way for the manufacturer to comply with standards set under different regulatory alternatives. If the limits (and technology cost-effectiveness) prevent enough manufacturers from meeting the required levels of stringency, the agency may decide that the standards under consideration may not be economically practicable. The difference between the required fuel economy level that applies to a manufacturer's fleet and the level of fuel economy that the agency projects the manufacturer would achieve in that year, based on our analysis, is called a "compliance shortfall."[64]

We underscore again that the modeling analysis does not dictate the "answer," it is merely one source of information among others that aids the agency's balancing of the standards. These considerations, shortfalls and increases in incremental technology costs, do not entirely define economic practicability, but we believe they are symptomatic of it. In looking at the projected compliance shortfall results from our modeling analysis, the agency preliminarily concluded, based on the information before us at the time, that for both passenger car and for light trucks, the MNB and TC=TB alternatives, and the 5%, 6% and 7% alternatives did not appear to be economically practicable, and were thus likely beyond maximum feasible levels for MYs 2017-2025. In other words, despite the theoretical technological feasibility of achieving these levels, various manufacturers would likely lack the financial and engineering resources and sufficient lead time to do so.

The analysis showed that for the passenger car 5% alternative, there were significant compliance shortfalls for Chrysler in MY 2025, Ford in MYs 2021 and 2023-2025, GM in MYs 2022 and 2024-2025, Mazda in MYs 2021 and 2024-2025, and Nissan in MY 2025. For light trucks, the analysis showed the 5% alternative had significant compliance shortfalls for Chrysler in MYs 2022-2025, Ford in MY 2025, GM in MYs 2023-2025, Kia in MY 2025, Mazda in MYs 2022 and 2025, and Nissan in MYs 2023-2025. However, the 4%, 3% and 2% alternatives did not appear, based on shortfalls, to be beyond the level of economic practicability, and thus appeared potentially to be within the range of alternatives that might yet be maximum feasible.

TABLE III.B.2-3. ESTIMATED PASSENGER CAR COMPLIANCE SHORTFALL FOR THE 5%/YEAR ALTERNATIVE (MPG)

Estimated Compliance Shortfall for Passenger Car (mpg)									
	2017	2018	2019	2020	2021	2022	2023	2024	2025

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[64] The agency's modeling estimates how the application of technologies *could* increase vehicle costs, reduce fuel consumption, and reduce CO_2 emissions, and affect other factors. As CAFE standards are performance-based, NHTSA does not mandate that specific technologies be used for compliance. CAFE modeling, therefore projects one way that manufacturers *could* comply. Manufacturers may choose a different mix of technologies based on their unique circumstances and products.

Chrysler	-	-	-	-	-	1.7	-	-	2.3
Ford	-	-	-	0.2	-	-	1.5	2.9	5.2
General Motors	-	-	-	-	-	2.3	0.8	2.1	2.5
Honda	-	-	-	-	-	-	-	-	-
Hyundai	-	-	-	-	-	-	-	-	-
Kia	-	-	-	-	-	-	-	-	-
Mazda	-	-	-	-	1.9	-	-	1.6	1.9
Nissan	-	-	-	-	-	-	-	-	1.3
Toyota	-	-	-	-	-	-	-	-	-

TABLE III.B.2-4. ESTIMATED LIGHT TRUCK COMPLIANCE SHORTFALL FOR THE 5%/YEAR ALTERNATIVE (MPG)

Estimated Compliance Shortfall for Light Truck (mpg)									
	2017	2018	2019	2020	2021	2022	2023	2024	2025
Chrysler	-	-	-	-	-	1.8	0.9	3.2	0.9
Ford	-	-	-	-	-	-	-	0.1	1.8
General Motors	-	-	-	-	-	0.1	1.8	3.2	2.9
Honda	-	-	-	-	-	-	-	-	0.6
Hyundai	-	-	-	-	-	-	0.6	-	-
Kia	-	-	-	-	-	-	-	-	2.1
Mazda	-	-	-	-	-	1.0	-	-	2.1
Nissan	-	-	-	-	-	-	1.1	2.1	4.6
Toyota	-	-	-	-	-	-	-	-	-

The preliminary analysis referred to above, in which the agency tentatively concluded that the 5%, 6%, 7%, MNB, and TC=TB alternatives were likely beyond the level of economic practicability based on the information available to the agency at the time, was conducted following the first SNOI and prior to the second SNOI – thus, between the end of 2010 and July 2011. The agencies stated in the first SNOI that we had not conducted sufficient analysis at the time to narrow the range of potential stringencies that had been discussed in the initial NOI and in the Interim Joint TAR, and that we would be conducting more analyses and continuing extensive dialogue with stakeholders in the coming months to refine our proposal. Based on our initial consideration of how the factors might be balanced to determine the maximum feasible standards to propose for MYs 2017-2025 (*i.e.*, where technological feasibility did not appear to be particularly limiting and the need of the nation would counsel for choosing more stringent alternatives, but economic practicability posed significant limitations), NHTSA's preliminary analysis indicated that the alternatives including up to 4% per year for cars and 4% per year for trucks should reasonably remain under consideration.

With that preliminary estimate of 4%/year for cars and trucks as the upper end of the range of alternatives that should reasonably remain under consideration for MYs 2017-2025, the agencies began meeting again intensely with stakeholders, including many individual manufacturers, between June 21, 2011 and July 27, 2011 to determine whether additional information would aid NHTSA in further consideration. Beginning in the June 21, 2011 meeting, NHTSA and EPA presented the 4% alternative target curves as a potential concept along with preliminary program flexibilities and provisions, in order to get feedback from the manufacturer stakeholders. Manufacturer stakeholders provided comments, much of which was confidential business information, which included projections of how they might comply with concept standards, the challenges that they expected, and their recommendations on program stringency and provisions.[65]

Regarding passenger cars, several manufacturers shared projections that they would be capable of meeting stringency levels similar to NHTSA's preliminary CAFE modeling projections for the 4% alternative in MY 2020 or in 2021, with some of those arguing that they faced challenges in the earlier years of that period with meeting a constant 4% rate throughout the entire period. Some manufacturers shared projections that they could comply with stringencies that ramped up, increasing more slowly in MY 2017 and then progressively increasing through MY 2021. Most manufacturers provided limited projections beyond MY 2021, although some stated that they could meet the agency's concept stringency targets in MY 2025. Manufacturers generally suggested that the most significant challenges to meeting a constant 4% (or faster) year-over-year increase in the passenger car standards related to their ability to implement the new technologies quickly enough to achieve the required levels, given their need to implement fuel economy improvements in both the passenger car and light truck fleets concurrently; challenges related to the cadence of redesign and refresh schedules; the pace at which new technology can be implemented considering economic factors such as availability of engineering resources to develop and integrate the technologies into products; and the pace at which capital costs can be incurred to acquire and integrate the manufacturing and production equipment necessary to increase the production volume of the technologies. Manufacturers often expressed concern that the 4% levels could require greater numbers of advanced technology vehicles than they thought they would be able to sell in that time frame, given their belief that the cost of some technologies was much higher than the agencies had estimated and their observations of current consumer acceptance of and willingness to pay for advanced technology vehicles that are available now in the marketplace. A number of manufacturers argued that they did not believe that they could create a sustainable business case under passenger car standards that increased at the rate required by the 4% alternative.

Regarding light trucks, most manufacturers expressed significantly greater concerns over the 4% alternative for light trucks than for passenger cars. Many manufacturers argued that increases in light truck standard stringency should be slower than increases in passenger car standard stringency, based on, among other things, the greater payload, cargo capacity and towing utility requirements of light trucks, and what they perceived to be lower consumer acceptance of certain (albeit not all) advanced technologies on light

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[65] Feedback from these stakeholder meetings is summarized in section IV.B and documents that are referenced in that section.

trucks. Many manufacturers also commented that redesign cycles are longer on trucks than they are on passenger cars, which reduces the frequency at which significant changes can be made cost-effectively to comply with increasing standards, and that the significant increases in stringency in the MY 2012-2016 program[66] in combination with redesign schedules would not make it possible to comply with the 4% alternative in the earliest years of the MY 2017-2025 program, such that only significantly lower stringencies in those years would be feasible in their estimation. As for cars, most manufacturers provided limited projections beyond MY 2021. Manufacturers generally stated that the most significant challenges to meeting a constant 4% (or faster) year-over-year increase in the light truck standards were similar to what they had described for passenger cars as enumerated in the paragraph above, but were compounded by concerns that applying technologies to meet the 4% alternative standards would result in trucks that were more expensive and provided less utility to consumers. As was the case for cars, manufacturers argued that their technology cost estimates were higher than the agencies' and consumers are less willing to accept/pay for some advanced technologies in trucks, but manufacturers argued that these concerns were more significant for trucks than for cars, and that they were not optimistic that they could recoup the costs through higher prices for vehicles with the technologies that would be needed to comply with the 4% alternative. Given their concerns about having to reduce utility and raise truck prices, and about their ability to apply technologies quickly enough given the longer redesign periods for trucks, a number of manufacturers argued that they did not believe that they could create a sustainable business case under light truck standards that increased at the rate required by the 4% alternative.

Other stakeholders, such as environmental and consumer groups, consistently stated that stringent standards are technically achievable and critical to important national interests, such as improving energy independence, reducing climate change, and enabling the domestic automobile industry to remain competitive in the global market. Labor interests stressed the need to carefully consider economic impacts and the opportunity to create and support new jobs, and consumer advocates emphasized the economic and practical benefits to consumers of improved fuel economy and the need to preserve consumer choice. In addition, a number of stakeholders stated that the standards under development should not have an adverse impact on safety.

NHTSA, in collaboration with EPA and in coordination with CARB, carefully considered the inputs received from all stakeholders, conducted additional independent analyses, and deliberated over the feedback received on the agencies' analyses. NHTSA considered individual manufacturers' redesign cycles and, where available, the level of technologies planned for their future products that improve fuel economy, as well as some estimation of the resources that would likely be needed to support those plans and the potential future standards. The agency also considered whether we agreed that there could conceivably be compromises to vehicle utility depending on the technologies chosen to meet the potential new standards, and whether a change in the cadence of the rate at which standards increase could provide additional opportunity for industry to develop

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[66] Some manufacturers indicated that their light truck fleet fuel economy would be below what they anticipated their required fuel economy level would be in MY 2016, and that they currently expect that they will need to employ available flexibilities to comply with that standard.

and implement technologies that would not adversely affect utility. NHTSA considered feedback on consumer acceptance of some advanced technologies and consumers' willingness to pay for improved fuel economy. In addition, the agency carefully considered whether manufacturer assertions about potential uncertainties in the agency's technical, economic, and consumer acceptance assumptions and estimates were potentially valid, and if so, what the potential effects of these uncertainties might be on economic practicability.

Regarding passenger cars, after considering this feedback from stakeholders, the agency considered further how it thought the factors should be balanced to determine the maximum feasible passenger car standards for MYs 2017-2025. Based on that reconsideration of the information before the agency and how it informs our balancing of the factors, NHTSA tentatively concludes that the points raised may indicate that the agency's preliminary analysis supporting consideration of standards that increased up to 4%/year may not have captured fully the level of uncertainty that surrounds economic practicability in these future model years. Nevertheless, while we believe there may be *some* uncertainty, we do not agree that it is nearly as significant as a number of manufacturers maintained, especially for passenger cars. The most persuasive information received from stakeholders for passenger cars concerned practicability issues in the first phase of the MY 2017-2025 standards. We therefore tentatively conclude that the maximum feasible stringency levels for passenger cars are only slightly different from the 4%/year levels suggested as the high end preliminarily considered by the agency; increasing on average 3.7%/year in MYs 2017-2021, and on average 4.5%/year in MYs 2022-2025. For the overall MY 2017-2025 period, the maximum feasible stringency curves increase on average at 4.1%/year, and our analysis indicates that the costs and benefits attributable to the 4% alternative and the preferred alternative for passenger cars are very similar: the preferred alternative is 8.8 percent less expensive for manufacturers than the 4% alternative (estimated total costs are $113 billion for the preferred alternative and $124 billion for the 4% alternative), and achieves only $20 billion less in total benefits than the 4% alternative (estimated total benefits are $310 billion for the preferred alternative and $330 billion for the 4% alternative), a very small difference given that benefits are spread across the entire lifetimes of all vehicles subject to the standards. The analysis also shows that the lifetime cumulative fuel savings is only 5 percent higher for the 4% alternative than the preferred alternative (the estimated fuel savings is 104 billion gallons for the preferred alternative, and 110 billion gallons for the 4% alternative).

At the same time, the increase in average vehicle cost in MY 2025 is 9.4 percent higher for the 4% alternative (the estimated cost increase for the average vehicle is $2,023 for the preferred alternative, and $2,213 for the 4% alternative). The rates of increase in stringency for each model year are summarized in Table IV.F.3 and Table IV.F.4. NHTSA emphasizes that under 49 U.S.C. 32902(b), the standards must be maximum feasible in each model year without reference to other model years, but we believe that the small amount of progressiveness in the proposed standards for MYs 2017-2021, which has very little effect on total benefits attributable to the proposed passenger car standards, will help to enable the continuation of, or increases in, research and development into the more advanced technologies that will enable greater stringency increases in MYs 2022-2025, and help to capture the considerable fuel savings and environmental benefits similar to the 4% alternative beginning in MY 2025.

We are concerned that requiring manufacturers to invest that capital to meet higher standards in MYs 2017-2021, rather than allowing them to increase fuel economy in those years slightly more slowly, would reduce the levels that would be feasible in the second phase of the program by diverting research and development resources to those earlier model years. Thus, after considerable deliberation with EPA and consultation with CARB, NHTSA selected the preferred alternative as the maximum feasible alternative for MYs 2017-2025 passenger cars based on consideration of inputs from manufacturers and the agency's independent analysis, which reaches the stringency levels of the 4% alternative in MY 2025, but has a slightly slower ramp up rate in the earlier years.

TABLE III.B.2-5. ANNUAL RATE OF INCREASE IN THE STRINGENCY OF THE PREFERRED ALTERNATIVE FOR EACH MODEL YEAR

Model Year	Passenger Car	Light Truck
2017	3.6%	0.6%
2018	3.6%	2.1%
2019	3.6%	1.7%
2020	3.7%	2.0%
2021	4.2%	6.4%
2022	4.5%	4.5%
2023	4.4%	4.7%
2024	4.5%	4.7%
2025	4.5%	4.6%

TABLE III.B.2-6. ANNUAL RATE OF INCREASE IN THE STRINGENCY OF THE PREFERRED ALTERNATIVE OVER VARIOUS PERIODS

Model Years	Passenger Car	Light Truck
2017-2021	3.7%	2.6%
2022-2025	4.5%	4.6%
2017-2025	4.1%	3.5%

Regarding light trucks, while NHTSA does not agree with the manufacturer's overall cost assessments and believe that our technology cost and effectiveness assumptions should allow the most capable manufacturers to preserve all necessary vehicle utility, the agencies do believe there is merit to some of the concerns raised in stakeholder feedback. Specifically, concerns about longer redesign schedules for trucks, compounded by the need to invest simultaneously in raising passenger car fuel economy, may not have been fully captured in our preliminary analysis. This could lead manufacturers to implement technologies that do not maintain vehicle utility, based on the cadence of the standards under the 4% alternative. A number of manufacturers repeatedly stated, in providing feedback, that the MYs 2012-2016 standards for trucks, while feasible, required significant investment to reach the required levels, and that given the redesign schedule for trucks, that level of investment throughout the entire MYs 2012-2025 time period was not sustainable. Based on the confidential business information that manufacturers provided to us, we believe that this point may be valid. If the agency pushes CAFE increases that require considerable sustained investment at a faster rate than industry redesign cycles, adverse economic consequences could ensue. The best information that the agency has at this time, therefore, indicates that requiring light truck fuel economy improvements at the 4% annual rate could create potentially severe economic consequences.

Thus, evaluating the inputs from stakeholders and the agency's independent analysis, the agency also considered further how it thought the factors should be balanced to determine the maximum feasible light truck standards for MYs 2017-2025. Based on that consideration of the information before the agency and how it informs our balancing of the factors, NHTSA tentatively concludes that 4%/year CAFE stringency increases for light trucks in MYs 2017-2021 are likely beyond maximum feasible, and in fact, in the earliest model years of the MY 2017-2021 period, that the 3%/year and 2%/year alternatives for trucks are also likely beyond maximum feasible. NHTSA therefore tentatively concludes that the preferred alternative, which would in MYs 2017-2021 increase on average 2.6%/year, and in MYs 2022-2025 would increase on average 4.6%/year, is the maximum feasible level that the industry can reach in those model years. For the overall MY 2017-2025 period, the maximum feasible stringency curves would increase on average 3.5%/year. The rates of increase in stringency for each model year are summarized in Table III.B.2-5 and Table III.B.2-6.

Our analysis indicates that the preferred alternative has 48 percent lower cost than the 4% alternative (estimated total costs are $44 billion for the preferred alternative and $83 billion for the 4% alternative), and the total benefits of the preferred alternative are 30 percent lower ($87 billion lower) than the 4% alternative (estimated total benefits are $206 billion for the preferred alternative and $293 billion for the 4% alternative), spread across the entire lifetimes of all vehicles subject to the standards. The analysis also shows that the lifetime cumulative fuel savings is 42 percent higher for the 4% alternative than the preferred alternative (the estimated fuel savings is 69 billion gallons for the preferred alternative, and 98 billion gallons for the 4% alternative). At the same time, the increase in average vehicle cost in MY 2025 is 54 percent higher for the 4% alternative (the estimated cost increase for the average vehicle is $1,578 for the preferred alternative, and $2,423 for the 4% alternative).

While these differences are larger than for passenger cars, NHTSA believes that standards set at these levels for these model years will help address concerns raised by manufacturer stakeholders and reduce the risk for adverse economic consequences, while at the same time ensuring most of the substantial improvements in fuel efficiency initially envisioned over the entire period and supported by other stakeholders. NHTSA believes that these stringency levels, along with the provisions for incentives for advanced technologies to encourage their development and implementation, and the agencies' expectation that some of the uncertainties surrounding consumer acceptance of new technologies in light trucks should have resolved themselves by that time frame based on consumers' experience with the advanced technologies, will enable these increases in stringency over the entire MY 2017-2025 period. Although, as stated above, the light truck standards must be maximum feasible in each model year without reference to other model years, we believe that standards set at the stated levels for MYs 2017-2021 and the incentives for advanced technologies for pickup trucks will create the best opportunity to ensure that the MY 2022-2025 standards are economically practicable, and avoid adverse consequences. The first phase of light truck standards, in that respect, acts as a kind of bridge to the second phase, in which industry should be able to realize considerable additional improvements in fuel economy.

The proposed standards also account for the effect of EPA's standards, in light of the agencies' close coordination and the fact that both sets of standards were developed together to harmonize as part of the National Program. Given the close relationship between fuel economy and CO_2 emissions, and the efforts NHTSA and EPA have made to conduct joint analysis and jointly deliberate on information and tentative conclusions,[67] the agencies have sought to harmonize and align their proposed standards to the greatest extent possible, consistent with their respective statutory authorities. In comparing the proposed standards, the agencies' stringency curves are equivalent, except for the fact that the stringency of EPA's proposed passenger car standards reflect the ability to improve GHG emissions through reductions in A/C system refrigerant leakage and the use of lower GWP refrigerants (direct A/C improvements),[68] and that EPA provides incentives for PHEV, EV and FCV vehicles, which NHTSA does not provide because statutory incentives have already been defined for these technologies. The stringency of NHTSA's proposed standards for passenger cars for MYs 2017-2025 align with the stringency of EPA's equivalent standards when these differences are considered.[69] NHTSA is proposing the preferred alternative based on the tentative determination of maximum feasibility as described earlier in the section, but, based on efforts NHTSA and EPA have made to conduct joint analysis and jointly deliberate on information and tentative conclusions, NHTSA has also aligned the proposed CAFE standards with EPA's proposed standards.

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[67] NHTSA and EPA conducted joint analysis and jointly deliberated on information and tentative conclusions related to technology cost, effectiveness, manufacturers' capability to implement technologies, the cadence at which manufacturers might support the implementation of technologies, economic factors, and the assessment of comments from manufacturers.

[68] As these A/C system improvements do not influence fuel economy, the stringency of NHTSA's preferred alternatives do not reflect the availability of these technologies.

[69] We note, however, that the alignment is based on the assumption that manufacturers implement the same level of direct A/C system improvements as EPA currently forecasts for those model years, and on the assumption of PHEV, EV, and FCV penetration at specific levels. If a manufacturer implements a higher level of direct A/C improvement technology and/or a higher penetration of PHEVs, EVs and FCVs, then NHTSA's proposed standards would effectively be more stringent than EPA's. Conversely, if a manufacturer implements a lower level of direct A/C improvement technology and/or a lower penetration of PHEVs, EVs and FCVs, then EPA's proposed standards would effectively be more stringent than NHTSA's.

Thus, consistent with President Obama’s announcement on July 29, 2011, and with the August 9, 2011 SNOI, NHTSA has tentatively concluded that the standards represented by the preferred alternative are the maximum feasible standards for passenger cars and light trucks in MYs 2017-2025. We recognize that higher standards would help the need of the nation to conserve more energy and might potentially be technologically feasible (in the narrowest sense) during those model years, but based on our analysis and the evidence presented by the industry, we tentatively conclude that higher standards would not represent the proper balancing for MYs 2017-2025 cars and trucks.[70] We tentatively conclude that the correct balancing recognizes economic practicability concerns as discussed above, and sets standards at the levels that the agency is proposing in this NPRM.[71] In the same vein, lower standards might be less burdensome on the industry, but considering the environmental impacts of the different regulatory alternatives as required under NEPA and the need of the nation to conserve energy, we do not believe they would have represented the appropriate balancing of the relevant factors, because they would have left technology, fuel savings, and emissions reductions on the table unnecessarily, and not contributed as much as possible to reducing our nation’s energy security and climate change concerns. Standards set at the proposed levels for MYs 2017-2021 will provide the additional benefit of helping to enable further research and development into the more advanced fuel economy-improving technologies to provide a bridge to more stringent standards in MYs 2022-2025, and enable significant fuel savings and environmental benefits throughout the program, and particularly substantial benefits in the later years of the program and beyond. Additionally, consistent with Executive Order 13563, the agency believes that the benefits of the preferred alternative amply justify the costs; indeed, the monetized benefits exceed the monetized costs by $358 billion over the lifetime of the vehicles covered by the proposed standards. In full consideration of all of the information currently before the agency, we have weighed the statutory factors carefully and selected proposed passenger car and light truck standards that we believe are the maximum feasible for MYs 2017-2025.

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[70] We note, for example, that while Executive Orders 12866 and 13563 focus attention on an approach that maximizes net benefits, both Executive Orders recognize that this focus is subject to the requirements of the governing statute. In this rulemaking, the standards represented by the “MNB” alternative are more stringent than what NHTSA has tentatively concluded would be maximum feasible for MYs 2017-2025, and thus setting standards at that level would be inconsistent with the requirements of EPCA/EISA to set maximum feasible standards. However, we believe that the proposed standards can be seen as maximizing net benefits subject to the statutory and other considerations inherent in the determination of maximum feasible standards.

[71] We underscore that the agency’s tentative decision regarding what standards would be maximum feasible for MYs 2017-2025 is made with reference to the rulemaking time frame and circumstances of this proposal. Each CAFE rulemaking (indeed, each stage of any given CAFE rulemaking) presents the agency with new information that may affect how we balance the relevant actors.

IV. IMPACT OF OTHER GOVERNMENTAL VEHICLE STANDARDS ON FUEL ECONOMY

Introduction

The Energy Policy and Conservation Act (EPCA or the Act) requires that fuel economy standards for passenger cars and light trucks be set at the maximum feasible level after considering the following criteria: (1) technological feasibility, (2) economic practicability, (3) the impact of other Government standards on fuel economy, and (4) the need of the Nation to conserve energy. Using MY 2008 as a baseline, this section discusses the effects of other government regulations on model year (MY) 2017-2025 passenger car and light truck fuel economy. These effects have not been included in the Volpe model at this time. Based on our analysis and preliminary indications from industry, the agency is assuming that the manufacturers will be able to reduce overall weight by an average of 15 percent net compared to MY 2008 vehicles, such that if weight is added to meet the requirements imposed by the regulations discussed here, more weight will need to be removed from vehicles in order to reach the assumed net 15 percent reduction.

The Impact on Weight of Safety Standards and Voluntary Safety Improvements

The fuel economy impact of safety improvements will typically take the form of increased vehicle weight, which reduces the fuel economy of the vehicle. The agency's estimates are based on cost and weight tear-down studies of a few vehicles and cannot possibly cover all the variations in the manufacturers' fleets, but are meant to be rough averages of potential per-vehicle costs that could be incurred.

We have broken down our analysis of the impact of safety standards that might affect the MY 2017-25 fleets into two parts: 1) those NHTSA final rules with known effective dates, and 2) proposed rules or potential rules in NHTSA's priority plan that could become effective before MY 2025, but do not have effective dates at this time.

Weight Impacts of Required Safety Standards (Final Rules)

The National Highway Traffic Safety Administration (NHTSA) has issued several safety standards that become effective for passenger cars and light trucks between MY 2008 and MY 2018. We will examine the potential impact on passenger car and light truck weights for these final rules using MY 2008 as a baseline.

1. FMVSS 126, Electronic Stability Control
2. FMVSS 202a, Head Restraints
3. FMVSS 206, Door Locks
4. FMVSS 208, 5th Female 35 mph Tests
5. FMVSS 214, Side Impact Oblique Pole Test
6. FMVSS 216, Roof Crush
7. FMVSS 226, Ejection Mitigation
8. FMVSS 301, Fuel System Integrity

FMVSS 126, Electronic Stability Control
The phase-in schedule for vehicle manufacturers is:

Table IV-1
Electronic Stability Control Effective Dates Phase-in Schedule

Model Year	Production Beginning Date	Requirement
2009	September 1, 2008	55% with carryover credit
2010	September 1, 2009	75% with carryover credit
2011	September 1, 2010	95% with carryover credit
2012	September 1, 2011	All light vehicles

The final rule requires all light vehicles to meet the ESC requirements by MY 2012. In comparison, the MY 2008 voluntary compliance was estimated as shown in Table IV-2.

Table IV-2
MY 2008 Voluntary Compliance

	Passenger Cars	Light Trucks
ABS and ESC	36%	64%
ABS alone	46%	35%
No systems	18%	1%

The agency's analysis[72] of weight impacts found that ABS adds 10.7 lbs. and ESC adds 1.8 lbs. per vehicle for a total of 12.5 lbs. Based on confidential manufacturers' plans for voluntary installation of ESC in MY 2008, 82 percent of passenger cars would have ABS and 36 percent would have ESC. Thus, the MY 2008 weight added by the manufacturers' plans for passenger cars would be 9.42 lbs. (0.82*10.7 + 0.36*1.8) and for light trucks would be 11.75 lbs. (0.99 x 10.7 + 0.64*1.8).

The incremental weight for the period of MY 2017-2025 compared to the MY 2008 baseline is 3.08 lbs. for passenger cars (12.5 – 9.42 lbs) and 0.75 lbs. for light trucks (12.5 – 11.75 lbs.) for the ESC requirements.

FMVSS 202a, Head Restraints
An amendment to the head restraints rule increased the height of head restraint by an estimated 1.3 inches and reduced backset, which brought the head restraint closer to the back of the head. The phase-in starts with MY 2010. The average weight increase is estimated by NHTSA to be about 3 pounds for both passenger cars and light trucks.

FMVSS 206, Door locks
A new door lock test for sliding doors took effect in MY 2009. This test was expected to force those sliding doors that used a latch/pin mechanism to change to two latches to help

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[72] "Final Regulatory Impact Analysis, FMVSS 126, Electronic Stability Control Systems", March 2007, NHTSA, Docket No. 2007-27662-2.

keep sliding doors closed during crashes. The increase in weight is estimated to be 1.0 lbs. Several van models had two sliding doors. Out of 1.4 million MY 2003 vans an estimated 1.2 million doors needed to be changed to the two latch system. Given that vans were 13.2 percent of light truck sales in MY 2007, it is estimated that in MY 2009, average light truck weight would be increased by 0.11 lbs. for sliding door latches (1.2/1.4 million * 0.132 * 1 lb.). No increase in weight is anticipated for passenger cars.

FMVSS 208, Occupant Crash Protection – 35 mph belted 50th percentile male and 5th percentile female testing

The agency phased-in requirements for 35 mph belted testing with the 50th percentile male were 35 percent for MY 2008, 65 percent for MY 2009, and 100 percent for MY 2010. The agency phased-in requirements for 35 mph belted testing with the 5th percentile female were 35 percent for MY 2010, 65 percent for MY 2011, and 100 percent for MY 2012. Several different technologies could be used to pass this test, but the agency's analysis of these countermeasures showed no increase in weight was needed.

FMVSS 214, Oblique Pole Side Impact Test

Based on the phase-in requirements for the side impact oblique pole test, all vehicles must meet the test by MY 2017. A teardown study of five thorax air bags resulted in an average weight increase per vehicle of 4.77 pounds (2.17 kg).[73] A second study[74] performed teardowns of 5 window curtain systems. One of the window curtain systems was very heavy (23.45 pounds). The other four window curtain systems had an average weight increase per vehicle of 6.78 pounds (3.08 kg), a figure which we assumed to be average for all vehicles in the future.

Based on MY 2008 confidential information supplied by manufacturers to NHTSA, most vehicles already currently provide head and thorax protection. The estimated percentage of vehicles with side air bags with head protection was 99.5 percent of passenger cars and 97.2 percent of light trucks and torso protection was estimated at 93.0 percent of passenger cars and 82.5 percent of light trucks. This information indicates that the weight increases for the head and thorax air bag countermeasures for the FMVSS 214 oblique pole test for the MY 2017 and later vehicles compared to a MY 2008 baseline are 0.37 lbs. for passenger cars and 1.02 lbs. for light trucks.

During make/model testing, the agency noted that some vehicles did not pass the chest deflection criteria even with thorax air bags. This means that additional structure may have to be added for some vehicles. Based on information provided in the last fuel economy rulemaking from several manufacturers, the side structure of many vehicles has been increased due to the side oblique pole test. An average estimate of the weight added per vehicle is 12.85 pounds for both passenger cars and light trucks. Based on MY 2008

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[73] Khadilkar, et al. "Teardown Cost Estimates of Automotive Equipment Manufactured to Comply with Motor Vehicle Standard – FMVSS 214(D) – Side Impact Protection, Side Air Bag Features", April 2003, DOT HS 809 809.

[74] Ludtke & Associates, "Perform Cost and Weight Analysis, Head Protection Air Bag Systems, FMVSS 201", page 4-3 to 4-5, DOT HS 809 842.

certification data, an estimated 6.1 percent of passenger cars and 17.9 percent of light trucks certified compliance to the oblique pole test requirements. Thus, an estimate of the increased structural weight that will be added between MY 2008 and MY 2017 is 12.07 pounds for passenger cars and 10.55 pounds for light trucks {(1 - .061)*12.85 pounds and (1 - .179)*12.85 pounds}.

Combined, the total weight added for FMVSS 214 oblique pole test between MY 2008 and MY 2017 is estimated to be 12.43 pounds (0.37 + 10.05) for passenger cars and 11.57 pounds (1.02 + 10.55) for light trucks.

FMVSS 216, Roof Crush

On May 12, 2009, NHTSA issued a final rule amending the roof crush standard from 1.5 times the vehicle weight to 3.0 times the vehicle weight for passenger cars and light trucks of 6,000 lbs. GVWR or less.[75] Vehicles over 6,000 lbs. and less than 10,000 lbs. GVWR will be required to meet the same test but at 1.5 times the vehicle weight. This rule will apply to all passenger cars and light trucks by MY 2017. In the FRIA, the average passenger car and light truck weight was estimated to increase weight by 7.9 to 15.4 lbs. The average weight of 11.65 lbs. will be used in this analysis.

FMVSS 226 Ejection Mitigation

On January 19, 2011, the agency published a final rule on ejection mitigation.[76] The final rule will result in larger window curtain side air bags and for a rollover sensor to be installed. Based on cost/weight tear down studies, the agency estimates that there will be a weight increase of 0.73 pounds for air bag material and 1.27 pounds for a larger inflator for a total of 2.0 pounds for passenger cars. The rollover sensor has a very minor weight. For light trucks, of which about 72 percent will have 3 rows of curtain coverage instead of 2 rows in most passenger cars, this estimate is increased by 25 percent to 2.5 pounds. Thus, for the average light truck the estimate is 2.36 pounds (0.72*2.5 + 0.28* 2.0).

FMVSS 301 Fuel System Integrity

NHTSA issued a final rule changing the rear impact test procedure to a 50 mph offset test. The phase-in effective dates are 40 percent for MY 2007, 70 percent for MY 2008, and 100 percent for MY 2009. Thus, an incremental 30 percent of the fleet needs to meet the standard in comparison to the MY 2008 baseline. Several different countermeasures could be used to meet the standard. Averaging the most likely two resulted[77] in an estimated 3.7 lbs. to passenger cars and light trucks. Assuming an incremental 30 percent of the fleet for MY 2009 at 3.7 lbs., results in an increase of 1.11 lbs. for the average vehicle.

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[75] Final Regulatory Impact Analysis, FMVSS 216 Upgrade Roof Crush Resistance, (Docket No. NHTSA-2009-0093-0004) (May 12, 2009) (74 FR 22347)

[76] 76 FR 3212, January 19, 2011, The Final Regulatory Impact Analysis is in Docket No. NHTSA-2011-0004-0003.

[77] Improvements in the fuel filler neck and redesigning areas around the fuel tank shield, for example a deformed gusset plate punctured the fuel tank wall.

Weight Impacts of proposed or potential rules that might affect MY 2017 and later vehicles

Based on NPRMs that the agency has issued, and based on projects in the priority plan, the agency has selected a list of rulemakings that might also affect weight in the rulemaking time frame. There is no guarantee that these projects will become final rules. Unless an NPRM has been issued, the weight estimates for these projects remain uncertain, since we would not have an actual proposed alternative to determine the stringency of the proposal.

1. FMVSS 111, Rear Visibility (Cameras)
2. Pedestrian Protection
3. Forward Collision Warning and Crash Imminent Braking
4. Lane Departure Warning
5. Oblique/Low Offset Frontal Collision
6. Event Data Recorders (EDR)

FMVSS 111, Rear Visibility

On December 7, 2008, the agency issued a notice of proposed rulemaking (NPRM) on rear visibility for passenger cars and light trucks. At this point it appears that cameras are the only countermeasure that could meet all the criteria of the proposal. Based on the preliminary results of a tear down study, we estimate the weight of a camera assembly with the display in the mirror at 0.32 lbs., and a camera assembly with the display on the dash at 0.50 lbs. Assuming a 50-50 split in these two display methods, the average weight increase would be 0.41 lbs. Based on sales information, only a small percent of passenger cars had cameras for MY 2008 and about 5 percent of the light trucks had cameras. While a larger percent of the fleet has cameras as an option in MY 2008, the agency does not have sales figures or take rates on those optional systems to update those percentages. Thus, the incremental weights are estimated to be 0.41 lbs. for passenger cars and 0.39 lbs. for light trucks.

Pedestrian Protection

The agency currently expects to propose the Global Technical Regulation on pedestrian protection. The effective dates have not been decided. Potential weight increases for pedestrian head and leg protection have not yet been identified, but the leg protection part of the standard has the potential to add many pounds to the front of the vehicle to extend the front end with softer material (perhaps 20 or more pounds).

Forward Collision Warning and Crash Imminent Braking

This is a research project in the priority plan that would add about 2 pounds to each vehicle, including having a radar in the front of the vehicle and possibly a camera behind the mirror facing forward, and wiring to a computer and the brakes.

Lane Departure Warning

This is another research project that would add about 2 pounds to each vehicle. It could use the same camera behind the mirror and could be connected to a computer and the steering system if lane keeping is part of the system.

Oblique/Low Offset Frontal Collision

The agency has made no decisions on this research project yet, but it does have the potential to add many pounds to the front of the vehicle (20-40 lbs) to have structure on the corners of the vehicle.

Part 563 Event Data Recorders

The agency anticipates about 1.0 pound of additional wiring or modules will be required by some manufacturers to meet future potential standards in this area. At this time, this only includes requiring the current voluntary standard and does not include other potential updates which have not been proposed.

Voluntary Measures that could affect weight

There are other voluntary measures that some manufacturers have identified as potentially increasing weight substantially. These include:

New NCAP tests – these have yet to be proposed, so their impact is not known.

IIHS testing of a narrow frontal pole test – how much overlap there is between meeting this test and the oblique/low offset frontal collision is not known. Potentially the same countermeasures could be designed to meet both projects.

Summary – Overview of Anticipated Weight Increases

Table IV-3 summarizes estimates made by NHTSA regarding the weight added by the above discussed standards or potential rulemakings. NHTSA currently estimates that weight additions required by final rules will add 33.27 pounds for passenger cars and 30.55 pounds for light trucks. With more uncertainty, we have estimated weight impacts of potential NHTSA regulations that would be effective by MY 2025, compared to the MY 2008 fleet, would increase weight by 45.4 to 65.4 pounds for passenger cars and light trucks. The combined weight increase of these safety standards are estimated at 78.68 to 98.68 pounds for passenger cars and 75.94 to 95.9 pounds for light trucks.

Table IV-3

NHTSA ESTIMATES

Weight Additions Due to Final Rules or Potential NHTSA Regulations
Comparing MY 2025 to the MY 2008 Baseline fleet

Final Rules by FMVSS No.	Passenger Cars Added Weight (pounds)	Passenger Cars Added Weight (kilograms)	Light Trucks Added Weight (pounds)	Light Trucks Added Weight (kilograms)
126 ESC	2.12	0.96	0.29	0.13
202a Head Restraints	0.60	0.27	0.60	0.27
206 Door Locks	0.00	0.00	0.11	0.05
208 5th Female 35 mph Test	0.00	0.00	0.00	0.00
214 Side Pole Test	12.43	5.64	11.57	5.25
216 Roof Crush	11.65	5.28	11.65	5.28
226 Ejection Mitigation	2.00	0.91	2.36	1.07
301 Fuel Tank	1.11	0.50	1.11	0.50
Final Rules Subtotal	33.27	15.09	30.55	13.86

Potential Rules				
111 Rear Cameras	0.41	0.19	0.39	0.18
Pedestrian Protection	20.00	9.07	20.00	9.07
Forward Collision Warning	2.00	0.91	2.00	0.91
Lane Departure Warning	2.00	0.91	2.00	0.91
Oblique/Offset Frontal	20.00 - 40.00	9.07 - 18.14	20.00 - 40.00	9.07 - 18.14
Part 563 EDR	1.00	0.45	1.00	0.45
Potential Rules Subtotal	45.41 - 65.41	20.60 - 29.67	45.29 - 65.39	20.59 - 29.66
Total	78.68 – 98.68	35.69 – 44.76	75.94 – 95.94	34.45 - 43.52

[CONFIDENTIAL
Table IV-4 provides a comparison of NHTSA estimates to those provided confidentially by

Table IV-4

CONFIDENTIAL DATA

Weight Additions Due to Final Rules or Potential NHTSA Regulations

Comparing MY 2025 to the MY 2010 Baseline fleet
PASSENGER CARS (in pounds)

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V. FUEL ECONOMY ENHANCING TECHNOLOGIES AND THE VOLPE MODEL

What attribute and mathematical function do the agencies use, and why?

As in the MYs 2012-2016 CAFE rule, and as NHTSA did in the MY 2011 CAFE rule, NHTSA is proposing to set attribute-based CAFE 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.[78] Public comments on the MYs 2012-2016 rulemaking widely supported attribute-based standards.

Under an attribute-based standard, every vehicle model has a fuel economy target, the level of which depends on the vehicle's attribute (for this proposal, footprint, as discussed below). The manufacturers' fleet average performance is determined by the harmonic production-weighted[79] average of those targets.

NHTSA believes an attribute-based standard is preferable to a single-industry-wide average standard in the context of CAFE 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 level applicable to every manufacturer).
Second, depending on the attribute, attribute-based standards reduce the incentive for manufacturers to respond to CAFE standards in ways harmful to safety.[80] Because 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.[81]

Third, attribute-based standards provide a more equitable regulatory framework for different vehicle manufacturers.[82] 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-

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[78] 49 U.S.C. 32902(a)(3)(A).

[79] Production for sale in the United States.

[80] 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.

[81] Assuming that the attribute is related to vehicle size.

[82] *Id*. at 4-5, finding 10.

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 are required to invest in technologies that improve the fuel economy of the vehicles they sell rather than shifting the 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.

As in the MYs 2012-2016 CAFE rules, and as NHTSA did in the MY 2011 CAFE rule, NHTSA is proposing to set CAFE 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 believes that footprint is the most appropriate attribute on which to base the standards, even though some other vehicle attributes (notably curb weight) are better correlated to fuel economy and emissions.

First, in the agency's 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 in any way less safe. While NHTSA's research of historical crash data also indicates that reductions in vehicle mass that are accompanied by reductions in vehicle footprint tend to compromise vehicle safety, footprint-based standards provide an incentive to use advanced lightweight materials and structures that would be discouraged by weight-based standards, because manufacturers can use them to improve a vehicle's fuel economy and CO_2 emissions without their use necessarily resulting in a change in the vehicle's fuel economy and emissions targets.

Further, although we recognize that weight is better correlated with fuel economy 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. As presented in NHTSA's MY 2011 CAFE final rule,[83] we anticipate that the possibility of gaming 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 levels projected by the agency.

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

NHTSA recognizes 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, NHTSA continues to believe that there will not be significant shifts in this distribution as a direct consequence of this proposed rule. The agency 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. NHTSA anticipates 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. NHTSA continues to find that footprint is the most appropriate attribute upon which to base the proposed standards, but recognizing strong public interest in this issue, we seek comment on whether the agency should consider setting standards for the final rule based on another attribute or another combination of attributes. If commenters suggest that the agency should consider another attribute or another combination of attributes, we specifically request that commenters address the concerns raised in the paragraphs above 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.

For the MY 2011 CAFE rule, NHTSA estimated fuel economy levels after normalization for differences in technology.[84] 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 distortional incentives for vehicles with neighboring footprints.[85]

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

[85] *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.

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.[86] 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 fleet-wide fuel economy and CO_2 emission levels for cars and light trucks described in the final rule.[87]

By requiring NHTSA to set CAFE standards that are attribute-based and defined by a mathematical function, Congress appears to have wanted 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.[88] The relationship between fuel economy and footprint, though directionally clear (*i.e.*, fuel economy tends to decrease 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.[89] There is thus a range of legitimate options open to NHTSA in developing curve shapes. The agency may of course consider statutory objectives in choosing among the many reasonable alternatives. For example, curve shapes that might have some theoretical basis could lead to perverse outcomes contrary to the intent of the statute to conserve energy.[90] 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 a normative aspect, where the agency adjusts the function that would define the relationship in order to avoid perverse results, improve equity of burden across manufacturers, 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 our choice of "cut-points" (if any) that define the fuel

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[86] 75 FR at 25362

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

[88] 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.

[89] In fact, numerous manufacturers have confidentially shared with the agencies what they described 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.

[90] 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.

economy and footprints at each end of the curves where the curves become flat. Data informs these decisions, but how the agency defines and interprets the relevant data, and then the choice of methodology for fitting a curve to the data, must include a consideration of both technical concerns and policy goals.

Each of the CAFE standards that NHTSA is proposing today for passenger cars and light trucks is expressed as a mathematical function that defines a fuel economy target applicable to each vehicle model and, for each fleet, establishes a required CAFE level determined by computing the sales-weighted harmonic average of those targets. We emphasize that whenever NHTSA shows required CAFE mpg levels, they are estimated required levels based on NHTSA's current projection of manufacturers' vehicle fleets in MYs 2017–2025. Actual required levels are not determined until the end of each model year, when all of the vehicles produced by a manufacturer in that model year are known and their compliance obligation can be determined with certainty. The target curves, as defined by the constrained linear function, and as embedded in the function for the sales-weighted harmonic average, are the real "standards."

NHTSA has determined passenger car fuel economy targets using a constrained linear function defined according to the following formula:

$$TARGET = \frac{1}{MIN\left[MAX\left(c \times FOOTPRINT + d, \frac{1}{a}\right), \frac{1}{b}\right]}$$

Here, *TARGET* is the fuel economy target (in mpg) applicable to vehicles of a given footprint (*FOOTPRINT*, in square feet), *b* and *a* are the function's lower and upper asymptotes (also in mpg), respectively, *c* is the slope (in gallons per mile per square foot) of the sloped portion of the function, and *d* is the intercept (in gallons per mile) of the sloped portion of the function (that is, the value the sloped portion would take if extended to a footprint of 0 square feet. The *MIN* and *MAX* functions take the minimum and maximum, respectively of the included values.

NHTSA is proposing, consistent with the standards for MYs 2011-2016, that the CAFE level required of any given manufacturer be determined by calculating the production-weighted harmonic average of the fuel economy targets applicable to each vehicle model:

$PRODUCTION_i$ is the number of units produced for sale in the United States of each i^{th} unique footprint within each model type, produced for sale in the United States, and $TARGET_i$ is the corresponding fuel economy target (according to the equation shown above and based on the corresponding footprint), and the summations in the numerator and denominator are both performed over all unique footprint and model type combinations in the fleet in question.

The proposed standards for passenger cars are, therefore, specified by the four coefficients defining fuel economy targets:
a = upper limit (mpg)
b = lower limit (mpg)
c = slope (gallon per mile per square foot)
d = intercept (gallon per mile)

For light trucks, NHTSA is proposing to define fuel economy targets in terms of a mathematical function under which the target is the maximum of values determined under each of two constrained linear functions. The second of these establishes a “floor” reflecting the MY 2016 standard, after accounting for estimated adjustments reflecting increased air conditioner efficiency. This prevents the target at any footprint from declining between model years. The resultant mathematical function is as follows:

The proposed standards for light trucks are, therefore, specified by the eight coefficients defining fuel economy targets:
a = upper limit (mpg)
b = lower limit (mpg)
c = slope (gallon per mile per square foot)
d = intercept (gallon per mile)
e = upper limit (mpg) of “floor”
f = lower limit (mpg) of “floor”
g = slope (gallon per mile per square foot) of “floor”
h = intercept (gallon per mile) of “floor”

As discussed in the draft joint TSD prepared by NHTSA and EPA, for the NPRM which this PRIA accompanies, the agencies reevaluated options for developing standards specified by the mathematical functions shown above. In doing so, the agencies sought to balance multiple technical concerns and policy considerations, such as implications for highway safety, potential risks that fuel economy and greenhouse gas reduction benefits will be less than expected, and relative compliance burdens on full-line and limited-line manufacturers. In considering how to address the various policy concerns discussed in the previous sections, the agencies revisited the market forecast and technology estimates, 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 the TSD, and in the preamble to today’s proposed rule, in NHTSA’s judgment, there is no single “correct” way to estimate the relationship between 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. Therefore, as described below and in detail in the agencies' joint TSD, NHTSA considered a range of different ways to adjust the data and statistically fit curves that could be used to develop standards.

Beginning with the agencies' joint MY 2008-based market forecast (described in Chapter 1 of the TSD), NHTSA performed a range of regressions describing the relationship between a vehicle's fuel consumption and its footprint. Because the relationship between fuel economy and CO_2 emission changes with fuel type, NHTSA excluded diesels and dedicated alternative fuel vehicles. As discussed in the joint TSD, the agency fitted curves to fuel economy levels as in the MY 2008 fleet; to fuel economy levels reflecting the addition of technologies as described above; and to fuel economy levels also reflecting adjustments based on differences considered 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" (horsepower-to-weight and weight-to-footprint ratios). These adjustments are presented in detail in the joint TSD.

NHTSA previously rejected adjustments based on normalizing factors because such adjustments have the potential to produce a virtually flat standard,[91] they imply that a multi-attribute standard may be necessary,[92] and the agency judged multi-attribute standard to be more subject to gaming than a footprint-only standard.[93] Notwithstanding these concerns, considering the policy concerns raised in connection with the shapes of the attribute-based standards, NHTSA, working jointly with EPA, determined that the agencies should reexamine the application of such normalization factors, and selected power-to-weight and weight-to-footprint ratios for evaluation. The agencies could have examined other potential factors, such as torque, engine displacement and cylinder count, load ratings (*e.g.*, towing capacity, GVWR, GCWR), interior volume, seating capacity, frontal area, and other vehicle attributes that could be related to fuel economy; NHTSA invites comment on whether such factors should be considered for purposes of fitting curves defining final fuel economy standards. NHTSA also invites comment on whether,

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[91] The potential to produce a flat standard arises if the normalizations remove sufficient explanatory power from footprint as an attribute related to fuel economy. NHTSA observed such an outcome when normalizing for differences in power-to-weight ratios in 2006, based on the market forecast and technology estimates the agency was applying at the time. Considering this, NHTSA reached the following conclusion: "NHTSA has experimented with normalizing footprint by horsepower-to-weight ratio. The result was a nearly flat standard with respect to footprint across the most popular size ranges. This did not appear to deliver the benefits of an attribute-based system. In addition, it involves significant downward adjustments to the fuel economy of hybrid electric vehicles (such as the Toyota Prius), for which the engine is not the sole source of motive power. Also, it involves significant upward adjustments to the fuel economy of vehicles with high power-to-weight ratios (such as the Chevrolet Corvette). Some of these upward and downward adjustments are large enough to suggest radical changes in the nature of the original vehicles. Furthermore, insofar as such normalization implies that NHTSA should adopt a two-attributed standard (*e.g.*, in which the target depends on footprint and power-to-weight ratio), it may be challenging and time consuming to come up with a sufficiently precise vehicle-by-vehicle definition of horsepower or horsepower-to-weight to be used for regulatory purposes." (73 FR 24437-24438)

[92] 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).

[93] 74 FR 14359.

and if so, the extent to which adjustments based on normalizing factors indicate that a standard expressed in terms of the same factors would be appropriate (*e.g.*, rather than using power-to-weight ratios to adjust fuel economy values used to fit a footprint-based function, should NHTSA promulgate a standard that depends on power-to-weight, rather than just on footprint?).

Using the footprint, fuel economy, and production (*i.e.*, number of units expected to be produced for sale in the United States) values resulting from the analysis described above and in the joint TSD, NHTSA fitted lines using combinations of the following statistical techniques: unweighted regression, in which each vehicle model type is treated as a unique observation; production-weighted regression, in which each unit produced is treated as unique observation; ordinary least squares (OLS) regression, in which the quality of the fit is measured in terms of the sum of the squared error terms; and minimum absolute deviation (MAD), in which the quality of the fit is measured in terms of the sum of the error terms' absolute values.

Previously, NHTSA elected to use unweighted regression because production-weighted regression gives the highest-sales vehicle model types vastly more emphasis than the lowest-sales vehicle models.[94] NHTSA also elected to use MAD rather than OLS because apparent outliers have less influence on the outcomes of MAD-based regression than they do on the outcomes of OLS-based regression (especially if production-weighted regression is performed and high-volume outliers are present), and NHTSA was unable to develop unambiguous criteria for identifying and rejecting outliers.[95] Notwithstanding these concerns, considering the policy concerns raised in connection with the shapes of the attribute-based standards, NHTSA, working jointly with EPA, determined that the agencies should include regression using production weighting and/or OLS among options explored for today's rulemaking. NHTSA invites comment on the advantages and disadvantages of production-weighted regression (as compared to unweighted regression), on the advantages and disadvantage of OLS (as compared to MAD and/or other robust regression techniques), and on any alternative regression techniques that could be applied for purposes of developing curves underlying attribute-based CAFE standards.

As discussed in the joint TSD, each combination of methods and data reflects a perspective, and the regression results simply 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.

For illustrative purposes, the set of figures below show the range of curves determined by the possible combinations of regression technique, 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 regressions, they describe the line that will result from minimizing the residuals or

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[94] 73 FR 24417-24429.

[95] *Ibid.*

squared residuals. 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 **Table V-3**, 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 V-3**.** 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 figure, for example, represents 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 various forms of adjustments described above to introduce other performance factors into the analysis, namely horsepower and weight, in the various ways described (whether horsepower to weight, weight to footprint, or both). Each of these adjustments has an influence on the regressions results, depicted in **Figure V-1** below.

Figure V-1
Best Fit Results for Various Regressions: Cars, No Added Technology, OLS

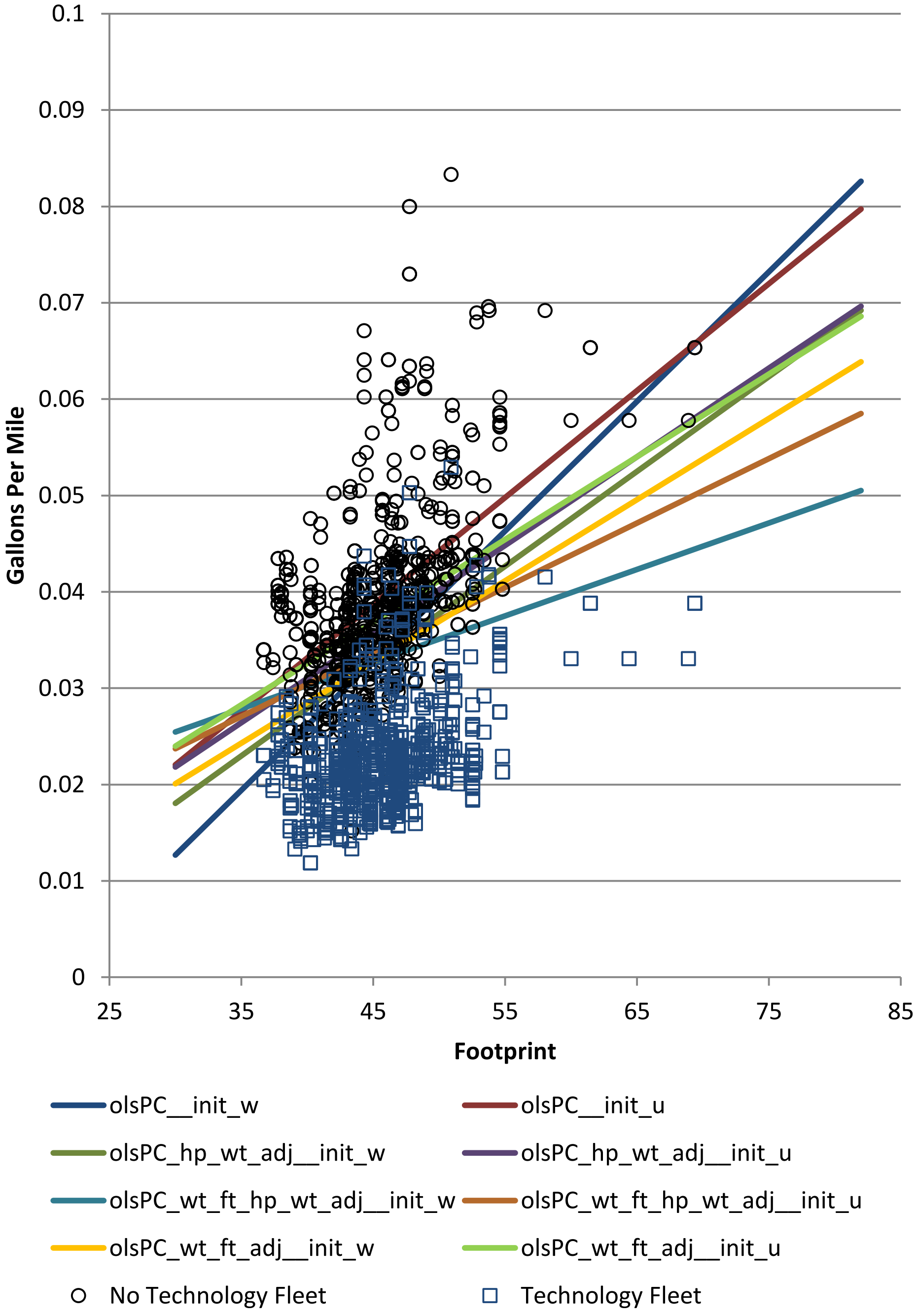
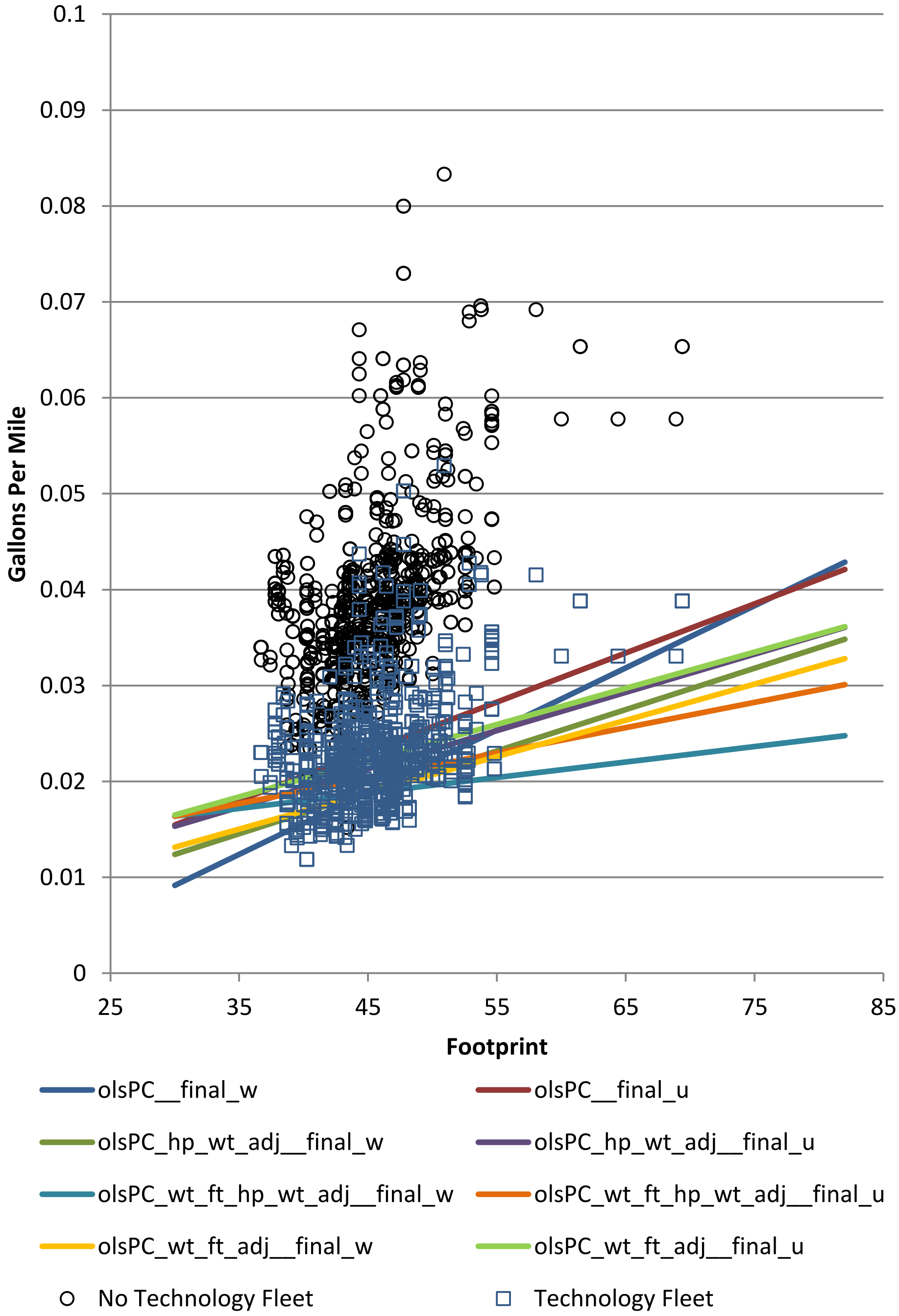


Figure V-2, below, shows comparable results, this time with data representing the additional technology that has been added to reduce technological heterogeneity. Note that the data now pass through the relevant data "cloud" for the Technology Fleet. The slopes of the lines are somewhat more clustered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

Figure V-2
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 V-3
Best Fit Results for Various Regressions: Trucks, No Added Technology, OLS

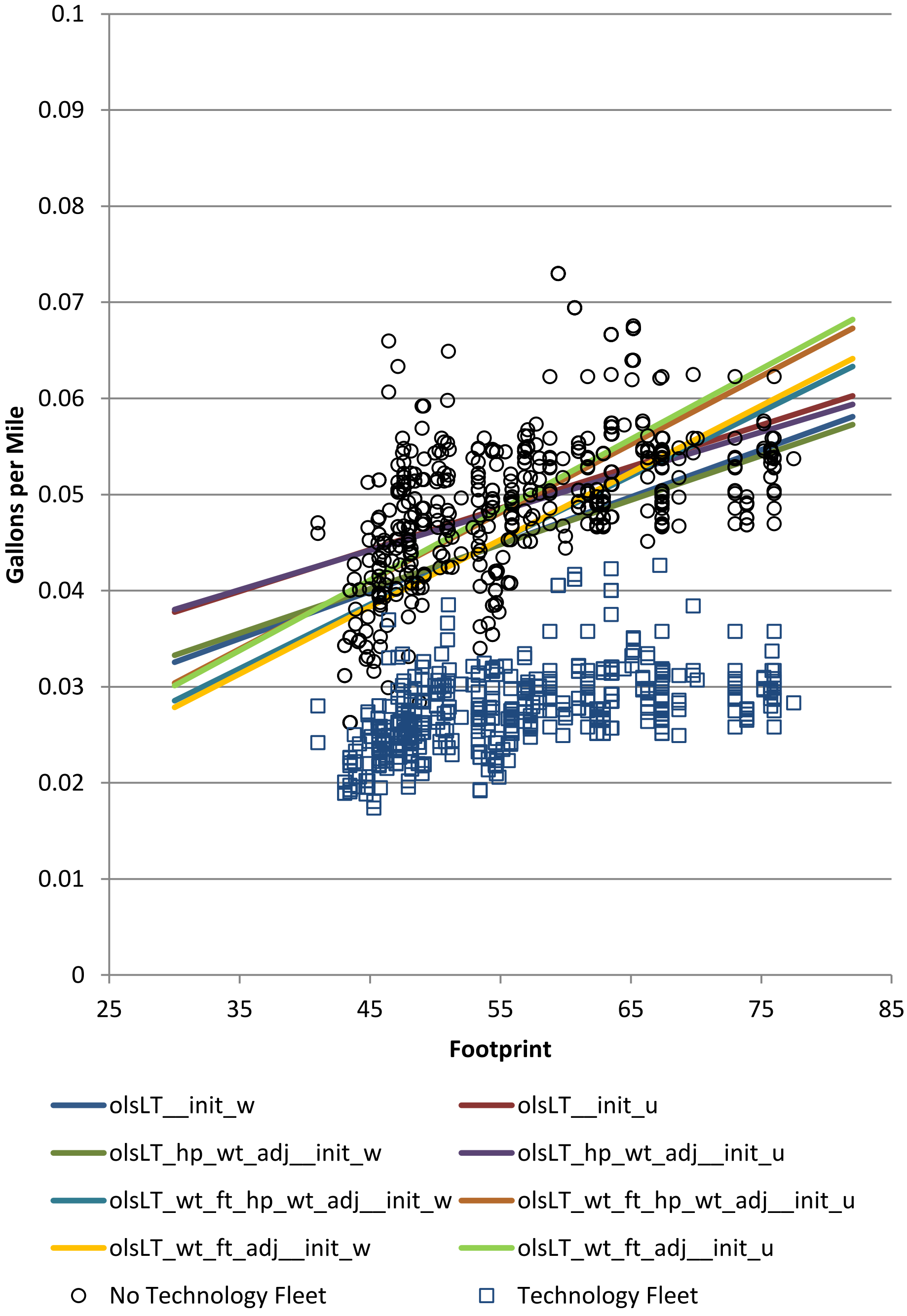


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Figure V-4
Best Fit Results for Various Regressions: Trucks, With Added Technology, OLS

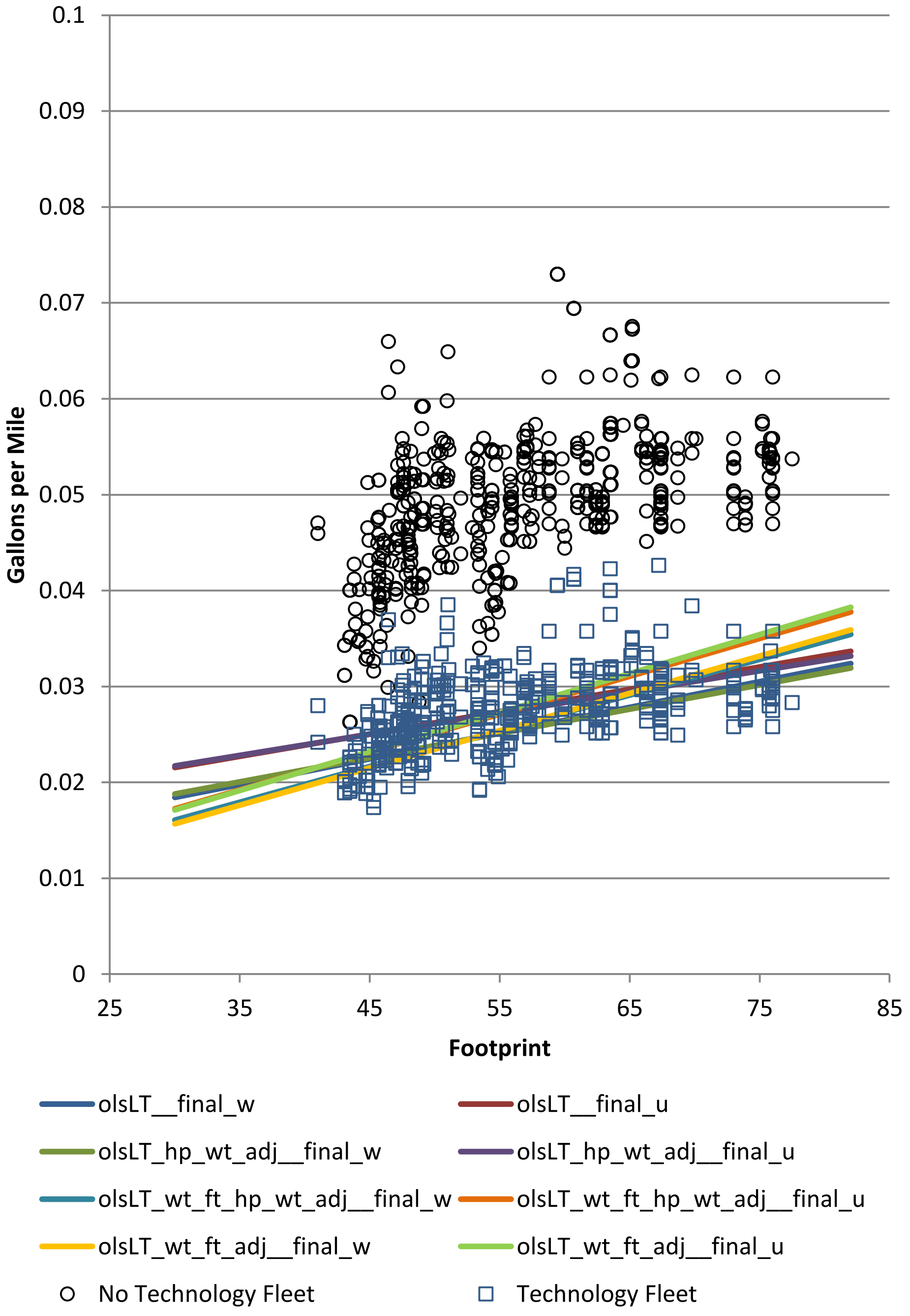


Figure V-5, below, displays regression results for the passenger car MAD best fits, which reduce the impact of outliers on the results. The results for the technology fleet do not demonstrate, however, the same degree of impact in reducing the difference in the attained slopes (with and without the addition of technology) evidenced in the OLS regressions.

Figure V-5
Best Fit Results for Various Regressions: Cars, No Added Technology, MAD

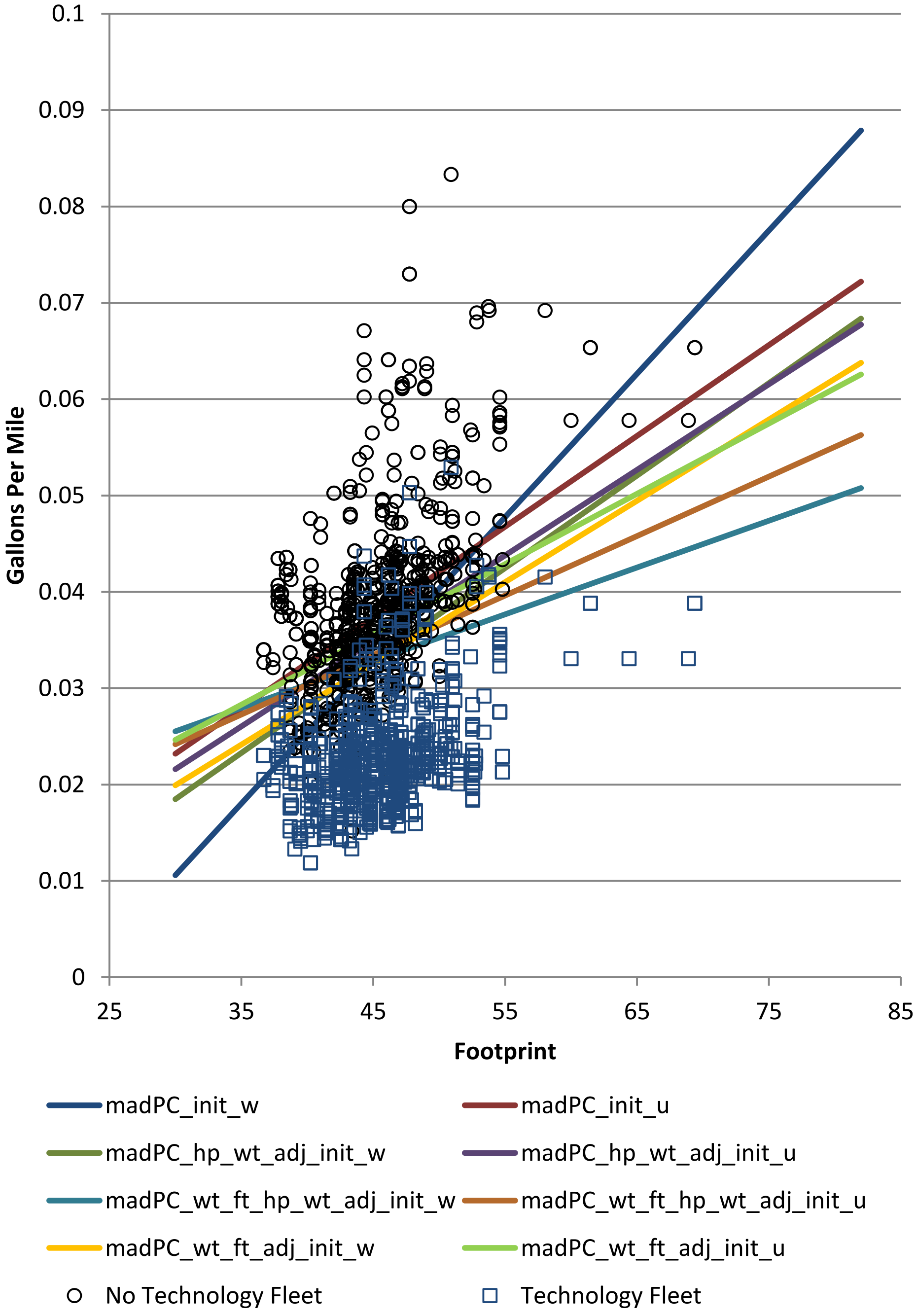
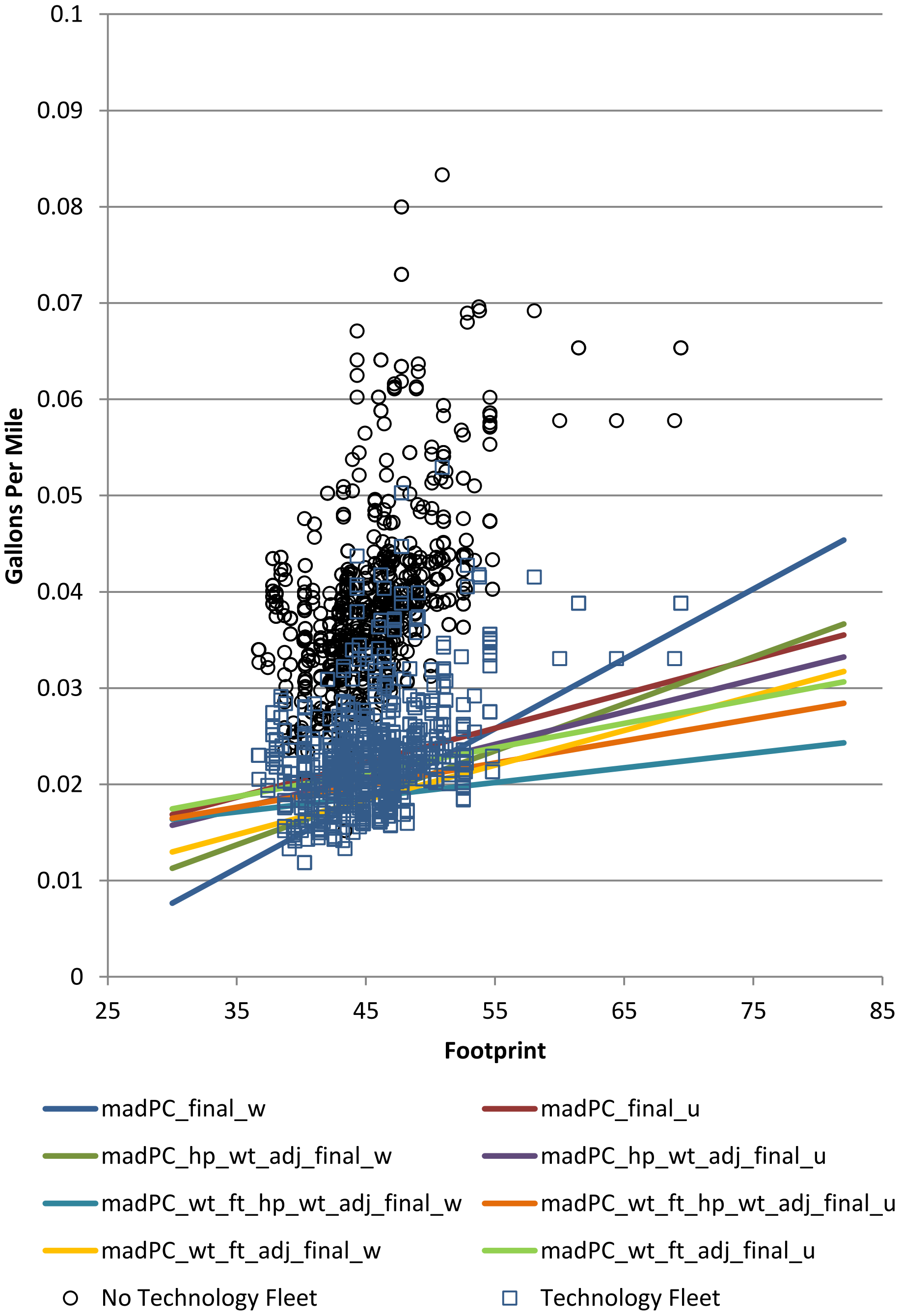


Figure V-6
Best Fit Results for Various Regressions: Cars, Added Technology, MAD



The MAD regression results below in Figure V-7 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 V-8, which can be ascribed to the reduction in heterogeneity of the fleet brought about by the addition of the technology.

Figure V-7
Best Fit Results for Various Regressions: Trucks, No Added Technology, MAD

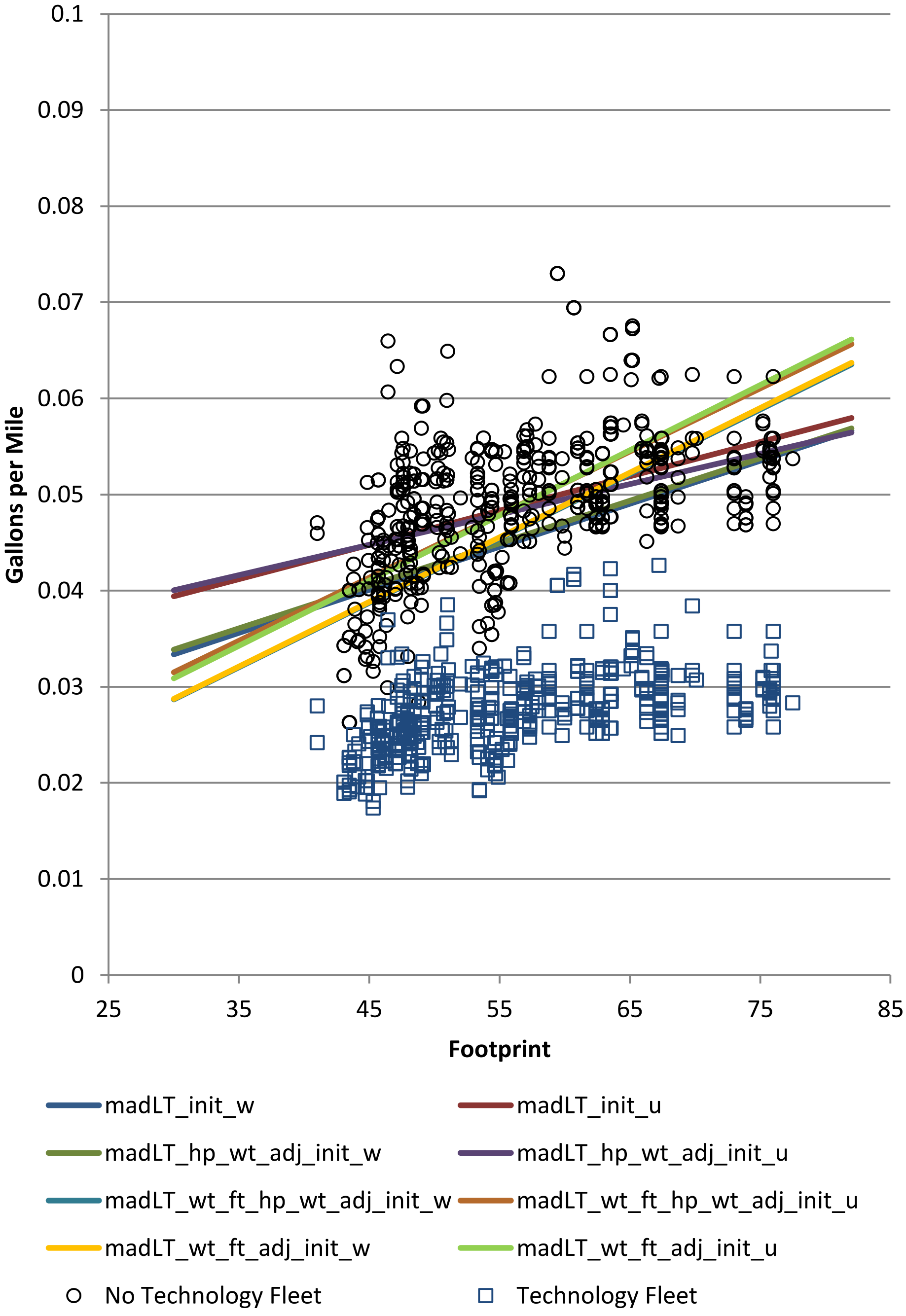
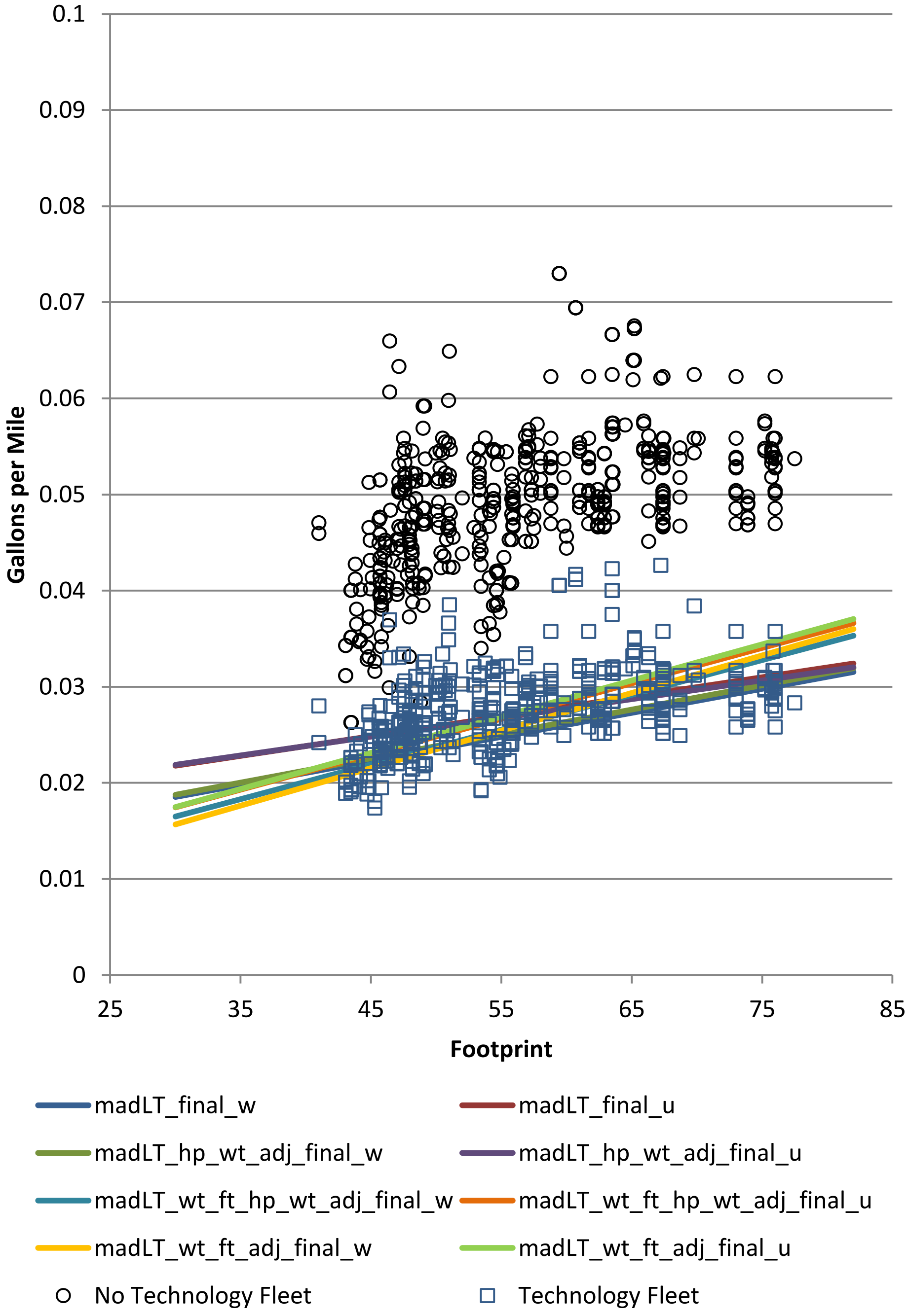


Figure V-8
Best Fit Results for Various Regressions: Trucks, with Added Technology, MAD



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. NHTSA believes that this represents a 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 analytical and policy matters, which include the statistical representativeness of the curves considered and the steepness of the curve chosen. NHTSA judges 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—of reducing variation in the data and thereby helping to estimate a relationship between fuel consumption/CO_2 and footprint.

Similarly, given the agencies' current MY 2008-based market-forecast and the agencies' current estimates of future technology effectiveness, the inclusion of the weight-to-footprint data adjustment prior to running the regression also helps to improve the fit of the curves by reducing the variation in the data, and NHTSA believes that the benefits of this adjustment for this proposed rule likely outweigh the potential that resultant curves might somehow encourage reduced load carrying capability or vehicle performance (note that the we are not suggesting that we believe these adjustments will reduce load carrying capability or vehicle performance). In addition to reducing the variability, the truck curve is also steepened, and the car curve flattened compared to curves fitted to sales-weighted data that do not include these normalizations. NHTSA agrees 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 weight per square foot would statistically suggest based on the agencies' current MY 2008-based market forecast and the agencies' current estimates of the effectiveness of different fuel-saving technologies. Therefore, it may be more equitable (*i.e.*, in terms of relative compliance challenges faced by different light truck manufacturers) to adjust the slope of the curve defining fuel economy targets.

The results of the normalized regressions are displayed in Table V-4, below.

Table V-4 – Regression Results

Vehicle	Slope (gallons/mile)	Constant (gallons/mile)
Passenger cars	0.000431	-0.00052489
Light trucks	0.0002526	0.01121968

As described above, however, other approaches are also technically reasonable, and also represent a way of expressing the underlying relationships. NHTSA plans to revisit the analysis for the final rule, after updating the underlying market forecast and estimates of technology effectiveness, and based on relevant public comments received. In addition, the agencies intend to update the technology cost estimates, which could alter the NPRM analysis results and consequently alter the balance of the trade-offs being weighed to determine the final 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 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).

Figure V-9
Gallons per Mile versus Footprint, Cars
(Data adjusted by weight to footprint).

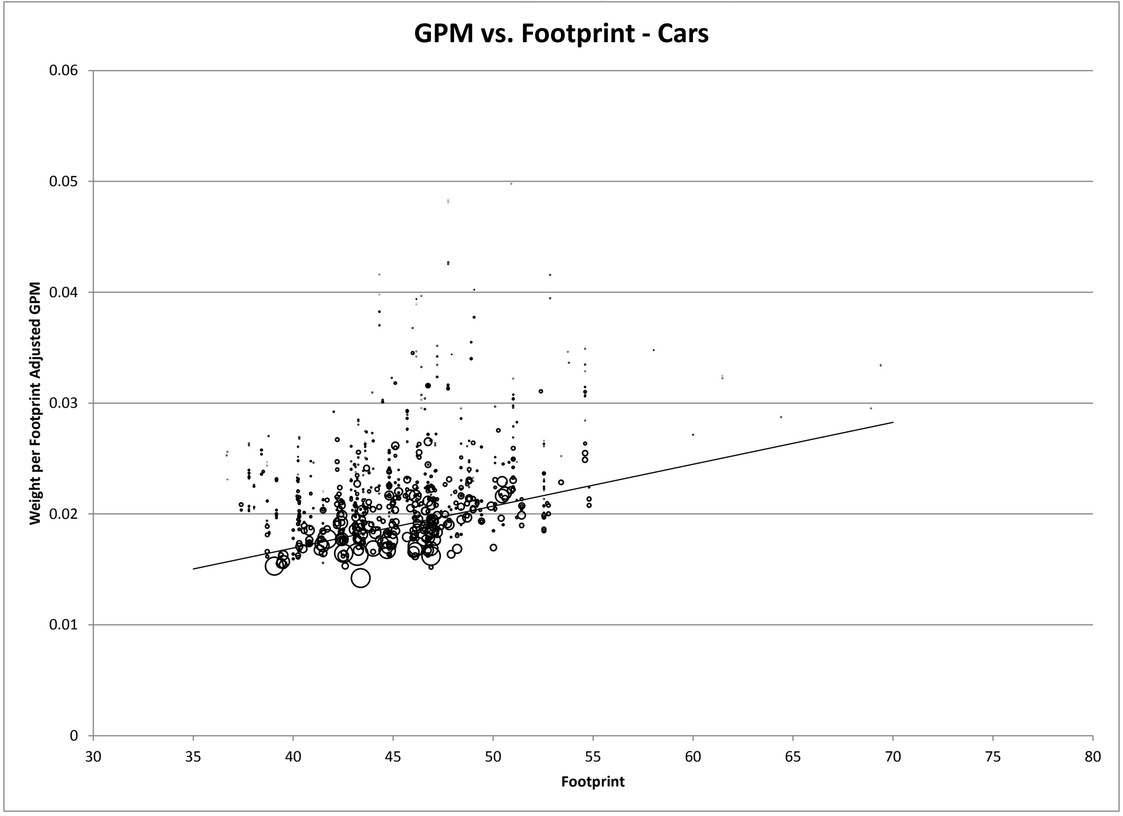
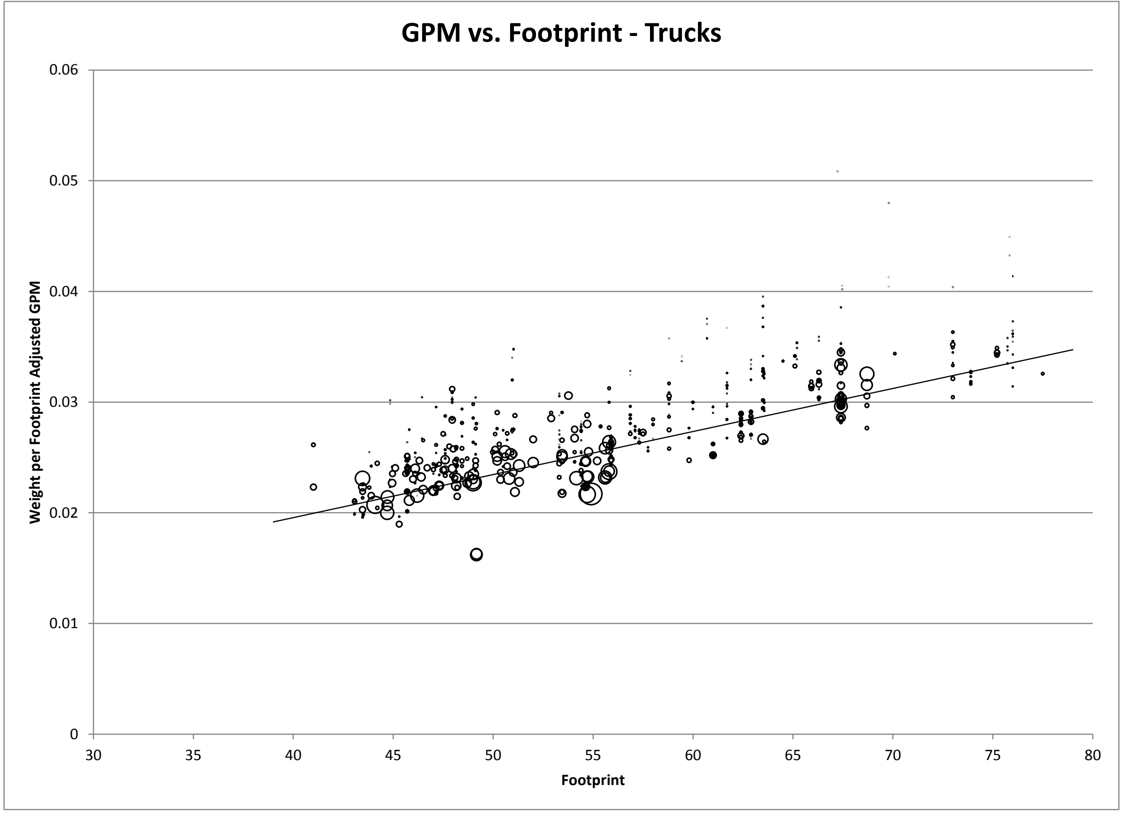


Figure V-9

Gallons per Mile versus Footprint, Trucks
(data adjusted by weight to footprint).



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. NHTSA notes with regard to light trucks that for the MYs 2012-2016 NPRM and final rule analyses, some models of pickups had been aggregated together, when, for example, the same pickup had been available in different cab configurations with different wheelbases.[96] For the current analysis, 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.

The proposed slope has several implications relative to the MY 2016 curves, with the majority of changes on the truck curve. With the agencies' current MY 2008-based market forecast and the agencies' current estimates of technology effectiveness, the combination of sales weighting and WT/FP normalization produced a car curve slope similar to that finalized in the MY 2012-2016 final 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.

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[96] *See* 75 FR at 25354

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 proposal, taking into account the updated market forecast and new assumptions about the availability of technologies. The next two sections discuss NHTSA's approach to cutpoints for the passenger car and light truck curves separately, as the policy considerations for each vary somewhat.

NHTSA continues 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.

The passenger car fleet upon which NHTSA has based the target curves for MYs 2017-2025 is 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 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, NHTSA is again proposing to cut off the sloped portion of the passenger car function at 41 square feet, consistent with the MYs 2012-2016 rulemaking. NHTSA recognizes 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. NHTSA thus believes 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, NHTSA notes that some manufacturers are introducing smaller 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 is therefore proposing again to cut off the sloped portion of the passenger car function at 56 square feet.

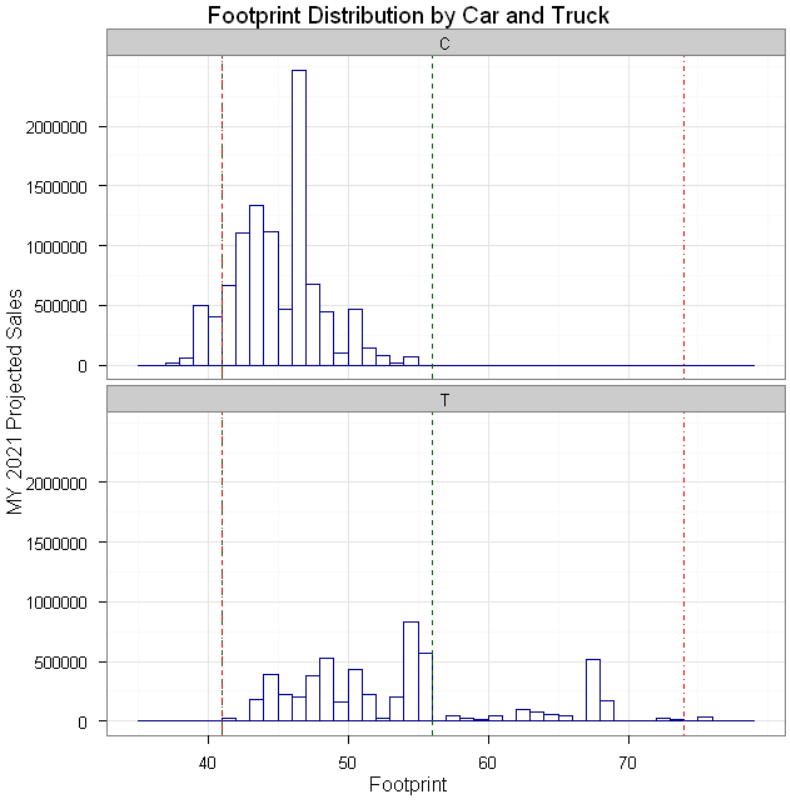
While meeting with manufacturers prior to issuing this proposal, the agencies received comments from some manufacturers that, combined with slope and overall stringency, using 41 square feet as the footprint at which to cap the target for small cars would result in unduly challenging targets for small cars. NHTSA does 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 are thus proposing to again “cut off” the passenger car curve at 41 square feet, notwithstanding these comments. NHTSA seeks comment on setting cutpoints for the MYs 2017-2025 passenger car curves at 41 square feet and 56 square feet.

The light truck fleet upon which the agencies have based the target curves for MYs 2017-2025, like the passenger car fleet, is derived from MY 2008 data, as also discussed above. In MY 2008, light truck footprints ranged from 41.0 square feet for the Jeep Wrangler, to 77.5 square feet for the Toyota Tundra. NHTSA is proposing to cut off the sloped portion of the light truck function at the same footprint, 41 square feet, although we recognize that no light trucks are currently offered below 41 square feet. With regard to the other cutpoint, NHTSA heard from a number of manufacturers during the discussions leading up to this proposal that the location of the cutpoint in the MYs 2012-2016 rules, 66 square feet, meant that the same standard applied to all light trucks with footprints of 66 square feet or greater, and that in fact the targets for the largest light trucks in the later years of that rulemaking were extremely challenging. Those manufacturers requested that NHTSA and EPA 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 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 NHTSA’s view, there is legitimate basis for these comments. NHTSA’s market forecast 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. While a relatively small portion of the overall truck fleet, for some manufacturers, these vehicles are non-trivial portion of 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 technologies in a way that maintains the full functionality of those capabilities.

Considering manufacturer CBI and our estimates of the impact of the 66 square foot cutpoint for future model years, NHTSA has initially 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 and our own analysis supports the gradual extension of the cutpoint for large light trucks in this proposal from 66 square feet in MY 2016 out to a larger footprint square feet before MY 2025.

Figure V-10 – Footprint Distribution by Car and Truck*



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

NHTSA is proposing 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—manufacturers should have no reason to remove fuel economy-improving technology from a vehicle once it has been applied. Put another way, the agencies are proposing to disallow "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."[97] The MY 2016 2-cycle test curves are therefore a floor in this proposal for the MYs 2017-2025 curves. The effect of making the MY 2016 curves a minimum level of stringency for the currently-proposed curves essentially affects only the light truck curves due to the proposed changes in slope and cut point for the truck curve relative to the MY 2016 truck curve. For passenger cars, which have minimal change in slope from the MY 2012-2016 rulemaking and no change in cut points, there are no curve crossing issues in the proposed standards.

The minimum stringency determination was done using the 2-cycle curves. Stringency adjustments for air conditioning and other credits were calculated after curves that did not cross were determined in 2-cycle space. The year-over-year increase in these adjustments do not cause the CAFE curves (with A/C) to contact the 2016 curve when charted.

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[97] 74 Fed. Reg. at 14370 (Mar. 30, 2009).

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 to reduce technological heterogeneity before performing statistical analysis, 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 paragraphs describe further adjustments to the curves discussed above that affect both the shape of the curve and the location of the curve, and that helped NHTSA determine curves that defined the proposed standards.

As in the MYs 2012-2016 rules, NHTSA developed curves defining regulatory alternatives for consideration by “shifting” these curves. For the MYs 2012-2016 rules, the agency did so on an absolute basis, offsetting the fitted curve by the same value (in gpm) at all footprints. In developing this proposal, NHTSA has reconsidered the use of this approach, and has concluded that after MY 2016, curves should be offset on a relative basis—that is, by adjusting the entire gpm-based 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) by a specific percentage of fuel consumption without the technology. It is, therefore, more consistent with the agencies’ estimates of technology effectiveness to develop the proposed standards and regulatory alternatives by applying a proportional offset to curves expressing fuel consumption 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 targets. Relative offsets avoid this potential outcome. Relative offsets do cause curves to become, on a fuel consumption 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, 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, NHTSA tentatively concludes 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. NHTSA invites comment on these conclusions, and on any other means that might avoid the potential outcomes—in particular, negative fuel consumption targets—discussed above.

The fuel economy values in the agencies’ market forecast 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). For the CAFE target curves, NHTSA is proposing for the first time to account for potential improvements in air conditioning system performance. Recognizing that there are significant and cost effective potential air conditioning system improvements available in the rulemaking timeframe (discussed in detail in Chapter 5 of the TSD), 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 is included based on air conditioning system efficiency improvements, as these improvements are the only improvements that effect vehicle fuel economy. As discussed above in Chapter 5 of the TSD, the air conditioning system improvements affect a vehicle's fuel efficiency emissions performance as an additive stringency increase, as compared to other fuel efficiency improving technologies that are multiplicative. Therefore, in adjusting target curves for improvements in the air conditioning system performance, NHTSA is adjusting the target curves by additive stringency increases (or vertical shifts) in the curves. NHTSA first uses 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 2-cycle performance. Then the curves are offset vertically by the air conditioning improvement by an equal amount at every point.

How does NHTSA use the assumptions in its modeling analysis?

In developing today's proposed CAFE standards, NHTSA has made significant use of results produced by the CAFE Compliance and Effects Model (commonly referred to as "the CAFE Model" or "the Volpe model"), which DOT's Volpe National Transportation Systems Center developed specifically to support NHTSA's CAFE rulemakings. The model, which has been constructed specifically for the purpose of analyzing potential CAFE standards, integrates the following core capabilities:

(1) Estimating how manufacturers could apply technologies in response to new fuel economy standards,
(2) Estimating the costs that would be incurred in applying these technologies,
(3) Estimating the physical effects resulting from the application of these technologies, such as changes in travel demand, fuel consumption, and emissions of carbon dioxide and criteria pollutants, and
(4) Estimating the monetized societal benefits of these physical effects.

An overview of the model follows below. Separate model documentation provides a detailed explanation of the functions the model performs, the calculations it performs in doing so, and how to install the model, construct inputs to the model, and interpret the model's outputs. Documentation of the model, along with model installation files, source code, and sample inputs are available at NHTSA's Web site. The model documentation is also available in the docket for today's proposed rule, as are inputs for and outputs from analysis of today's proposed CAFE standards.

How does the model operate?

As discussed above, the agency uses the Volpe model to estimate how manufacturers could attempt to comply with a given CAFE standard by adding technology to fleets that the agency anticipates they will produce in future model years. This exercise constitutes a simulation of manufacturers' decisions regarding compliance with CAFE standards.

This compliance simulation begins with the following inputs: (a) the baseline and reference market forecast discussed in Section II.B of the preamble, Chapter III above, and Chapter 1 of the draft joint TSD, (b) technology-related estimates discussed in Section II.D of the preamble, below in this Chapter, and Chapter 3 of the draft joint TSD, (c) economic inputs discussed in Section II.E of the preamble, Chapters VII and VIII below, and Chapter 4 of the draft joint TSD, and (d) inputs defining baseline and potential new CAFE standards, discussed in Section II.C of the preamble, and Chapter 2 of the draft joint TSD. For each manufacturer, the model applies technologies in a sequence that follows a defined engineering logic ("decision trees," discussed in the MY 2011 final rule and in the model documentation) and a cost-minimizing strategy in order to identify a set of technologies the manufacturer could apply in response to new CAFE standards.[98] The model applies technologies to each of the projected individual vehicles in a manufacturer's fleet, considering the combined effect of regulatory and market incentives. Depending on how the model is exercised, it will apply technology until one of the following occurs:

(1) The manufacturer's fleet achieves compliance[99] with the applicable standard, and continuing to add technology in the current model year would be attractive neither in terms of stand-alone (*i.e.*, absent regulatory need) cost effectiveness nor in terms of facilitating compliance in future model years;[100]
(2) The manufacturer "exhausts"[101] available technologies; or
(3) For manufacturers estimated to be willing to pay civil penalties, the manufacturer reaches the point at which doing so would be more cost-effective (from the manufacturer's perspective) than adding further technology.[102]

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[98] NHTSA does its best to remain scrupulously neutral in the application of technologies through the modeling analysis, to avoid picking technology "winners." The technology application methodology has been reviewed by the agency over the course of several rulemakings, and commenters have been generally supportive of the agency's approach. *See, e.g.,* 74 FR 14238–14246 (Mar. 30, 2009).

[99] The model has been modified to provide the ability—as an option—to account for credit mechanisms (*i.e.*, carry-forward, carry-back, transfers, and trades) when determining whether compliance has been achieved. For purposes of determining maximum feasible CAFE standards, NHTSA cannot consider these mechanisms, and exercises the CAFE model without enabling these options.

[100] In preparation for the MY2012-2016 rulemaking, the model was modified in order to apply additional technology in early model years if doing so will facilitate compliance in later model years. This is designed to simulate a manufacturer's decision to plan for CAFE obligations several years in advance, which NHTSA believes better replicates manufacturers' actual behavior as compared to the year-by-year evaluation which EPCA would otherwise require.

[101] In a given model year, the model makes additional technologies available to each vehicle model within several constraints, including (a) whether or not the technology is applicable to the vehicle model's technology class, (b) whether the vehicle is undergoing a redesign or freshening in the given model year, (c) whether engineering aspects of the vehicle make the technology unavailable (*e.g.,* secondary axle disconnect cannot be applied to two-wheel drive vehicles), and (d) whether technology application remains within "phase in caps" constraining the overall share of a manufacturer's fleet to which the technology can be added in a given model year. Once enough technology is added to a given manufacturer's fleet in a given model year that these constraints make further technology application unavailable, technologies are "exhausted" for that manufacturer in that model year.

[102] This possibility was added to the model to account for the fact that under EPCA/EISA, manufacturers must pay fines if they do not achieve compliance with applicable CAFE standards. 49 U.S.C. 32912(b). NHTSA recognizes that some manufacturers will find it more cost-effective to pay fines than to achieve compliance, and believes that to assume these manufacturers would exhaust available technologies before

As discussed below, the model has also been modified in order to—as an option—apply more technology than may be necessary to achieve compliance in a given model year, or to facilitate compliance in later model years. This ability to simulate "voluntary overcompliance," discussed elsewhere in this PRIA as a "market-driven baseline," reflects the potential that manufacturers will apply some technologies to some vehicles if doing so would be sufficiently inexpensive compared to the expected reduction in owners' outlays for fuel.

The model accounts explicitly for each model year, applying most technologies when vehicles are scheduled to be redesigned or freshened, and carrying forward technologies between model years. The CAFE model accounts explicitly for each model year because EPCA requires that NHTSA make a year-by-year determination of the appropriate level of stringency and then set the standard at that level, while ensuring ratable increases in average fuel economy.[103] The multiyear planning capability and (optional) simulation of "voluntary overcompliance" and EPCA credit mechanisms increase the model's ability to simulate manufacturers' real-world behavior, accounting for the fact that manufacturers will seek out compliance paths for several model years at a time, while accommodating the year-by-year requirement.

The model also calculates the costs, effects, and benefits of technologies that it estimates could be added in response to a given CAFE standard.[104] It calculates costs by applying the cost estimation techniques discussed herein, and by accounting for the number of affected vehicles. It accounts for effects such as changes in vehicle travel, changes in fuel consumption, and changes in greenhouse gas and criteria pollutant emissions. It does so by applying the fuel consumption estimation techniques also discussed herein, and the vehicle survival and mileage accumulation forecasts, the rebound effect estimate and the fuel properties and emission factors discussed in Chapter VIII below. Considering changes in travel demand and fuel consumption, the model estimates the monetized value of accompanying benefits to society, as also discussed in Chapter VIII

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paying fines would cause unrealistically high estimates of market penetration of expensive technologies such as diesel engines and strong hybrid electric vehicles, as well as correspondingly inflated estimates of both the costs and benefits of any potential CAFE standards. NHTSA thus includes the possibility of manufacturers choosing to pay fines in its modeling analysis in order to achieve what the agency believes is a more realistic simulation of manufacturer decision-making. Unlike flex-fuel and other credits, NHTSA is not barred by statute from considering fine-payment in determining maximum feasible standards under EPCA/EISA. 49 U.S.C. 32902(h).

[103] 49 U.S.C. 32902(a) states that at least 18 months before the beginning of each model year, the Secretary of Transportation shall prescribe by regulation average fuel economy standards for automobiles manufactured by a manufacturer in that model year, and that each standard shall be the maximum feasible average fuel economy level that the Secretary decides the manufacturers can achieve in that year. NHTSA has long interpreted this statutory language to require year-by-year assessment of manufacturer capabilities. 49 U.S.C. 32902(b)(2)(C) also requires that standards increase ratably between MY 2011 and MY 2020.

[104] As for all of its other rulemakings, NHTSA is required by Executive Order 12866 (as amended by Executive Order 13563) and DOT regulations to analyze the costs and benefits of CAFE standards. Executive Order 12866, 58 FR 51735 (Oct. 4, 1993); DOT Order 2100.5, "Regulatory Policies and Procedures," 1979, *available at http://regs.dot.gov/rulemakingrequirements.htm* (last accessed November 13, 2011).

below. The model calculates both the undiscounted and discounted value of benefits that accrue over time in the future.

The Volpe model has other capabilities that facilitate the development of a CAFE standard. The integration of (a) compliance simulation and (b) the calculation of costs, effects, and benefits facilitates analysis of sensitivity of results to model inputs. The model can also be used to evaluate many (*e.g.,* 200 per model year) potential levels of stringency sequentially, and identify the stringency at which specific criteria are met. For example, it can identify the stringency at which net benefits to society are maximized, the stringency at which a specified total cost is reached, or the stringency at which a given average required fuel economy level is attained. This allows the agency to compare more easily the impacts in terms of fuel savings, emissions reductions, and costs and benefits of achieving different levels of stringency according to different criteria. The model can also be used to perform uncertainty analysis (*i.e.,* Monte Carlo simulation), in which input estimates are varied randomly according to specified probability distributions, such that the uncertainty of key measures (*e.g.,* fuel consumption, costs, benefits) can be evaluated.

Has NHTSA considered other models?

As discussed in the most recent CAFE rulemaking, while nothing in EPCA requires NHTSA to use the Volpe model, and in principle, NHTSA could perform all of these tasks through other means, the model's capabilities have greatly increased the agency's ability to rapidly, systematically, and reproducibly conduct key analyses relevant to the formulation and evaluation of new CAFE standards.[105]

NHTSA notes that the Volpe model not only has been formally peer-reviewed and tested and reviewed through three rulemakings, but also has some features especially important for the analysis of CAFE standards under EPCA/EISA. Among these are the ability to perform year-by-year analysis, and the ability to account for engineering differences between specific vehicle models.

EPCA requires that NHTSA set CAFE standards for each model year at the level that would be "maximum feasible" for that year.[106] Doing so requires the ability to analyze each model year and, when developing regulations covering multiple model years, to account for the interdependency of model years in terms of the appropriate levels of stringency for each one. Also, as part of the evaluation of the economic practicability of the standards, as required by EPCA, NHTSA has traditionally assessed the annual costs and benefits of the standards. In response to comments regarding an early version of the CAFE model, DOT modified the CAFE model in order to account for dependencies between model years and to better represent manufacturers' planning cycles, in a way that still allowed NHTSA to comply with the statutory requirement to determine the appropriate level of the standards for each model year.

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[105] 75 FR 25598-25599.

The Volpe model is also able to account for important engineering differences between specific vehicle models, and to thereby reduce the risk of applying technologies that may be incompatible with or already present on a given vehicle model. By combining technologies incrementally and on a model-by-model basis, the CAFE model is able to account for important engineering differences between vehicle models and avoid unlikely technology combinations

The Volpe model also produces a single vehicle-level output file that, for each vehicle model, shows which technologies were present at the outset of modeling, which technologies were superseded by other technologies, and which technologies were ultimately present at the conclusion of modeling. For each vehicle, the same file shows resultant changes in vehicle weight, fuel economy, and cost. This provides for efficient identification, analysis, and correction of errors, a task with which the public can now assist the agency, since all inputs and outputs are public.

Such considerations, as well as those related to the efficiency with which the Volpe model is able to analyze attribute-based CAFE standards and changes in vehicle classification, and to perform higher-level analysis such as stringency estimation (to meet predetermined criteria), sensitivity analysis, and uncertainty analysis, lead the agency to conclude that the model remains the best available to the agency for the purposes of analyzing potential new CAFE standards.

What changes has DOT made to the model?

Between promulgation of the MY 2012-2016 CAFE standards and today's proposal regarding MY 2017-2025 standards, the Volpe model has been revised to make some minor improvements, and to add some significant new capabilities: (1) accounting for electricity used to charge electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs), (2) accounting for use of ethanol blends in flexible-fuel vehicles (FFVs), (3) accounting for costs (*i.e.*, "stranded capital") related to early replacement of technologies, (4) accounting for previously-applied technology when determining the extent to which a manufacturer could expand use of the technology, (5) applying technology-specific estimates of changes in consumer value, (6) simulating the extent to which manufacturers might utilize EPCA's provisions regarding generation and use of CAFE credits, (7) applying estimates of fuel economy adjustments (and accompanying costs) reflecting increases in air conditioner efficiency, (8) reporting privately-valued benefits, (9) simulating the extent to which manufacturers might voluntarily apply technology beyond levels needed for compliance with CAFE standards, and (10) estimating changes in highway fatalities attributable to any applied reductions in vehicle mass. These capabilities are described below, and in greater detail in the CAFE model documentation.[107]

To support evaluation of the effects electric vehicles (EVs) and plug-in hybrid vehicles (PHEVs) could have on energy consumption and associated costs and environmental

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[107] http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/CAFE+Compliance+and+Effects+Modeling+System:+The+Volpe+Model (last accessed: November 14, 2011)

effects, DOT has expanded the Volpe model to estimate the amount of electricity that would be required to charge these vehicles (accounting for the potential that PHEVs can also run on gasoline). The model calculates the cost of this electricity, as well as the accompanying upstream criteria pollutant and greenhouse gas emissions.

Similar to this expansion to account for the potential the PHEVs can be refueled with gasoline or recharged with electricity, DOT has expanded the Volpe model to account for the potential that other flexible-fuel vehicles can be operated on multiple fuels. In particular, the model can account for ethanol FFVs consuming E85 or gasoline, and to report consumption of both fuels', as well as, corresponding costs and upstream emissions.

Among the concerns raised in the past regarding how technology costs are estimated has been one that stranded capital costs be considered. Capital becomes "stranded" when capital equipment is retired or its use is discontinued before the equipment has been fully depreciated and the equipment still retains some value or usefulness. DOT has modified the CAFE model to, if specified for a given technology, when that technology is replaced by a newly applied technology, apply a stream of costs representing the stranded capital cost of the replaced technology. This cost is in addition to the cost for producing the newly applied technology in the first year of production.

As documented in prior CAFE rulemakings, the CAFE model applies "phase-in caps" to constrain technology application at the vehicle manufacturer level. They 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. This helps to ensure technological feasibility and economic practicability in determining the stringency of the standards. When the MY 2012-2016 rulemaking analysis was completed, the model performed the relevant test by comparing a given phase-in cap to the amount (*i.e.*, the share of the manufacturer's fleet) to which the technology had been added by the model. DOT has since modified the CAFE model to take into account the extent to which a given manufacturer has already applied the technology (*i.e.*, as reflected in the market forecast specified as a model inputs), and to apply the relevant test based on the total application of the technology.

The CAFE model requires inputs defining the technology-specific cost and efficacy (*i.e.*, percentage reduction of fuel consumption), and has, to date, effectively assumed that these input values reflect application of the technology in a manner that holds vehicle performance and utility constant. Considering that some technologies may, nonetheless, offer owners greater or lesser value (beyond that related to fuel outlays, which the model calculates internally based on vehicle fuel type and fuel economy), DOT has modified the CAFE model to accept and apply technology-specific estimates of any value gain realized or loss incurred by vehicle purchasers.[108]

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[108] For example, a value gain could be specified for a technology expected to improve ride quality, and a value loss could be specified for a technology expected to reduce vehicle range.

For the MY 2012-2016 CAFE rulemaking analysis, DOT modified the CAFE model to accommodate specification and accounting for credits a manufacturer is assumed to earn by producing flexible fuel vehicles (FFVs). Although NHTSA cannot consider such credits when determining maximum feasible CAFE standards, the agency presented an analysis that included FFV credits, in order to communicate the extent to which use of such credits might cause actual costs, effects, and benefits to be lower than estimated in NHTSA's formal analysis. As DOT explained at the time, it was unable to account for other EPCA credit mechanisms, because attempts to do so had been limited by complex interactions between those mechanisms and the multiyear planning aspects of the CAFE model. DOT has since modified the CAFE model to provide the ability to account for any or all of the following flexibilities provided by EPCA: FFV credits, credit carry-forward and carry-back (between model years), credit transfers (between passenger car and light truck fleets), and credit trades (between manufacturers). The model accounts for EPCA-specified limitations applicable to these flexibilities (*e.g.*, limits on the amount of credit that can be transferred between passenger car and light truck fleets). These capabilities in the model provide a basis for more accurately estimating costs, effects, and benefits that may actually result from new CAFE standards. Insofar as some manufacturers actually do earn and use CAFE credits, this provides NHTSA with the ability to examine outcomes more realistically than EPCA allows for purposes of setting new CAFE standards.

NHTSA is today proposing CAFE standards reflecting EPA's proposal to change fuel economy calculation procedures such that a vehicle's fuel consumption improvement will be accounted for if the vehicle has technologies that reduce the amount of energy needed to power the air conditioner. To facilitate analysis of these standards, DOT has modified the CAFE model to account for these adjustments, based on inputs specifying the average amount of improvement anticipated, and the estimated average cost to apply the underlying technology.

Considering that past CAFE rulemakings indicate that most of the benefits of CAFE standards are realized by vehicle owners, DOT has modified the CAFE model to estimate not just social benefits, but also private benefits. The model accommodates separate discount rates for these two valuation methods (*e.g.*, a 3% rate for social benefits with a 7% rate for private benefits). When calculating private benefits, the model includes changes in outlays for fuel taxes (which, as economic transfers, are excluded from social benefits) and excludes changes in economic externalities (*e.g.*, monetized criteria pollutant and greenhouse gas emissions).

Since 2003, the CAFE model (and its predecessors) have provided the ability to estimate the extent to which a manufacturer with a history of paying civil penalties allowed under EPCA might decide to add some fuel-saving technology, but not enough to comply with CAFE standards. In simulating this decision-making, the model considers the cost to add the technology, the calculated reduction in civil penalties, and the calculated present value (at the time of vehicle purchase) of the change in fuel outlays over a specified "payback period" (*e.g.*, 5 years). For a manufacturer assumed to be willing to pay civil penalties, the model stops adding technology once paying fines becomes more attractive than continuing to add technology, considering these three factors. As an extension of this simulation approach, DOT has modified the CAFE model to, if specified, simulate the potential that a manufacturer would add more technology than required for purposes of compliance with CAFE standards. When set to operate in this manner, the model will continue to apply technology to a manufacturer's CAFE-compliant fleet until applying further technology will incur more in cost than it will yield in calculated fuel savings over a specified "payback period" that is set separately from the payback period applicable until compliance is achieved. In its analysis supporting MY 2012-2016 standards adopted in 2010, NHTSA estimated the extent to which reductions in vehicle mass might lead to changes in the number of highway fatalities occurring over the useful life of the MY 2012-2016 fleet. NHTSA performed these calculations outside the CAFE model (using vehicle-specific mass reduction calculations from the model), based on agency analysis of relevant highway safety data. DOT has since modified the CAFE model to perform these calculations, using an analytical structure indicated by an update to the underlying safety analysis. The model also applies an input value indicating the economic value of a statistical life, and includes resultant benefits (or disbenefits) in the calculation of total social benefits.

In comments on recent NHTSA rulemakings, some reviewers have suggested that the Volpe model should be modified to estimate the extent to which new CAFE standards would induce changes in the prices of vehicles and therefore in the mix of vehicles in the new vehicle fleet. NHTSA agrees that a "market share" model, also called a consumer vehicle choice model, could provide useful information regarding the possible effects of potential new CAFE standards.

In response, NHTSA has contracted with GRA, Incorporated and the Brookings Institution to develop a vehicle choice model estimated at the vehicle configuration level that can be implemented as part of DOT's CAFE model. Also included in this contract are researchers based at the University of California – Davis and the University of California – Irvine. The Brookings-led researchers are utilizing data found in the National Household Transportation Survey to estimate realistic patterns of vehicle substitution and deferral of new vehicle purchases in response to changes in vehicle attributes, such as prices and fuel efficiency, which are caused by increases or decreases in the CAFE standards.

As discussed Section B.6 of Chapter V of the FRIA for MYs 2012-2016, past efforts by DOT staff demonstrated that a vehicle choice module could be added to the CAFE model, but previous efforts did not yield credible coefficients when specifying and estimating such a model. If a suitable and credibly calibrated vehicle choice model becomes available in time—whether through the Brookings-led research or from other sources—DOT may consider integrating a vehicle choice model into the CAFE model for the final rule or for subsequent rulemakings.

The results of the vehicle choice model developed in this study will be reviewed and evaluated in light of those from similar models described in published research, and their collective implications for vehicle buyers' valuation of fuel economy, performance, size, utility, and other vehicle attributes will be assessed. This assessment will then be integrated with a representation of vehicle manufacturers' behavior in response to a proposed fuel economy regulation drawn from the Volpe CAFE Compliance and Effects Modeling System. This integrated representation of new vehicle demand and supply will then be used to analyze the economic impacts of fuel economy regulations and other policies to reduce fuel consumption on vehicle buyers and owners, manufacturers, and the U.S. economy.

NHTSA anticipates this integration of a vehicle choice model would be structurally and operationally similar to the integration we implemented previously. As under the version applied in support of today's announcement, the CAFE model would begin with an agency-estimated market forecast, estimate to what extent manufacturers might apply additional fuel-saving technology to each vehicle model in consideration of future fuel prices and baseline or alternative CAFE standards and fuel prices, and calculate resultant changes in the fuel economy (and possibly fuel type) and price of individual vehicle models. With an integrated market share model, the CAFE model would then estimate how the sales volumes of individual vehicle models would change in response to changes in fuel economy levels and prices throughout the light vehicle market, possibly taking into account interactions with the used vehicle market. Having done so, the model would replace the sales estimates in the original market forecast with those reflecting these model-estimated shifts, repeating the entire modeling cycle until converging on a stable solution.

Based on past experience, we anticipate that this recursive simulation will be necessary to ensure consistency between sales volumes and modeled fuel economy standards, because achieved CAFE levels depend on sales mix and, under attribute-based CAFE standards, required CAFE levels also depend on sales mix. NHTSA anticipates, therefore, that application of a market share model would impact estimates of all of the following for a given schedule of CAFE standards: overall market volume, manufacturer market shares and product mix, required and achieved CAFE levels, technology application rates and corresponding incurred costs, fuel consumption, greenhouse gas and criteria pollutant emissions, changes in highway fatalities, and other economic benefits and/or costs.

Past testing by DOT/NHTSA staff did not indicate major shifts in broad measures (*e.g.*, in total costs or total benefits), but that testing emphasized shorter modeling periods (*e.g.*, 1-5 model years) and less stringent standards than reflected in today's proposal. Especially without knowing the characteristics of a future vehicle choice model, it is difficult to anticipate the potential degree to which its inclusion would impact analytical outcomes.

NHTSA invites comment on the above changes to the CAFE model. The agency's consideration of any alternative approaches will be facilitated by specific recommendations regarding implementation within the model's overall structure. NHTSA also invites comment regarding above-mentioned prospects for inclusion of a vehicle choice model. The agency's consideration will be facilitated by specific information demonstrating that inclusion of such a model would lead to more realistic estimates of costs, effects, and benefits, or that inclusion of such a model would lead to less realistic estimates.

Does the model set the standards?

Since NHTSA began using the Volpe model in CAFE analysis, some commenters have interpreted the agency's use of the model as the way by which the agency chooses the maximum feasible fuel economy standards. As the agency explained in its most recent CAFE rulemaking, this is incorrect.[109] Although NHTSA currently uses the Volpe model as a tool to inform its consideration of potential CAFE standards, the Volpe model does not determine the CAFE standards that NHTSA proposes or promulgates as final regulations. The results it produces are completely dependent on inputs selected by NHTSA, based on the best available information and data available in the agency's estimation at the time standards are set. Ultimately, NHTSA's selection of appropriate CAFE standards is governed and guided by the statutory requirements of EPCA, as amended by EISA: NHTSA sets the standard at the maximum feasible average fuel economy level that it determines is achievable during a particular model year, considering technological feasibility, economic practicability, the effect of other standards of the Government on fuel economy, and the need of the nation to conserve energy.

How does NHTSA make the model available and transparent?

Model documentation, which is publicly available in the rulemaking docket and on NHTSA's website, explains how the model is installed, how the model inputs (all of which are available to the public)[110] and outputs are structured, and how the model is used. The model can be used on any Windows-based personal computer with Microsoft Office 2003 or 2007 and the Microsoft .NET framework installed (the latter available without charge from Microsoft). The executable version of the model and the underlying source code are also available at NHTSA's Web site. The input files used to conduct the core analysis documented in this proposed rule are available in the public docket. With the model and these input files, anyone is capable of independently running the model to repeat, evaluate, and/or modify the agency's analysis.

Because the model is available with unrestricted access on NHTSA's web site, the agency has no way of knowing how widely the model has been used. The agency is, however, aware that the model has been used by other federal agencies, vehicle manufacturers, private consultants, academic researchers, and foreign governments. Some of these individuals have found the model complex and challenging to use. Insofar as the model's sole purpose is to help DOT staff efficiently analyze potential CAFE standards, DOT has not expended significant resources trying to make the model as "user friendly" as commercial software intended for wide use. However, DOT wishes to facilitate informed comment on the proposed standards, and encourages reviewers to contact the agency promptly if any difficulties using the model are encountered.

NHTSA arranged for a formal peer review of an older version of the model, has responded to reviewers' comments, and has considered and responded to model-related

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[109] 75 FR 25600.

[110] We note, however, that files from any supplemental analysis conducted that relied in part on confidential manufacturer product plans cannot be made public, as prohibited under 49 CFR part 512.

comments received over the course of four CAFE rulemakings. In the agency's view, this steady and expanding outside review over the course of nearly a decade of model development has helped DOT to significantly strengthen the model's capabilities and technical quality, and has greatly increased transparency, such that all model code is publicly available, and all model inputs and outputs are publicly available in a form that should allow reviewers to reproduce the agency's analysis. NHTSA is currently preparing arrangements for a formal peer review of the current CAFE model. Depending on the schedule for that review, DOT will consider possible model revisions and, as feasible, attempt to make any appropriate revisions before performing analysis supporting final CAFE standards for MY 2017 and beyond.

How does NHTSA determine a technology path to compliance with alternative CAFE standards?

The agency assumes, in this analysis, that manufacturers will add a variety of technologies to each of their vehicle models in order to improve their fuel economy performance. In order to evaluate proposed CAFE standards and regulatory alternatives, it is essential to understand what is feasible within the timeframe of the proposed rule. Determining the technological feasibility of proposed 2017-2025 standards requires a thorough study of the technologies expected to be 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 technology 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 cost as well as the technology penetration rate (or phase-in caps) that are assumed in the analysis. This chapter will also offer a detailed explanation of how NHTSA applies technologies to determine a feasible compliance path for the industry for the Preferred Alternative and the other regulatory alternatives analyzed by the agency in this rulemaking.

The agency considered technologies in many categories that manufacturers could use to improve the fuel economy 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 standards; such technologies would be part of the baseline fleet for this analysis[111]). Other technologies considered may not currently be in production, but are under development now 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 transmission—a combination that is not available today. These are technologies which the agency believes can, for the most part, be applied both to cars and trucks, and which are expected to achieve significant improvements in fuel economy at reasonable costs in the MYs 2017 to 2025 timeframe. The agency notes that we did not consider in

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[111] The technologies in the baseline fleet, which meets the MY 2016 CAFE standard, are projections made by NHTSA's CAFE model. Some technologies may be significantly represented in this baseline fleet.

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 this proposal. Examples of such technologies would be camless valve actuation and fuel cell vehicles.[112] The agency acknowledges that due to the relatively long period between the date of this proposal and the rulemaking timeframe, 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 agency plans to re-assess these technologies, along with all of the technologies considered in this proposal, as part of our mid-term evaluation.

How does NHTSA determine what technologies are already in the baseline vehicle fleet?

As in the MY 2012-2016 final rule, EPA in consultation with NHTSA developed the baseline fleet using the 2008 CAFE compliance data. The agencies then used EPA's emission certification and fuel economy database and a combination of publicly available data from sources like Ward's Automotive Group, Motortrend.com and Edmunds.com to determine the fuel-economy-improving/CO_2-reducing technologies already present in the individual baseline vehicles. The baseline fleet including the technologies already present on each vehicle is contained in the market data file model input. A more detailed discussion of how the baseline vehicle fleet was constructed can be found in Chapter III of this document and Chapter 1 of the draft joint TSD.

How does NHTSA determine what technologies can be applied beyond those in the baseline vehicle fleet?

As discussed above, many of the technologies considered for the MY 2017-2025 timeframe are the same ones considered for the MY 2012-2026 rulemaking, which are available in varying degrees today and which the agency will be able to be incorporated more fully throughout the fleet between now and 2025. NHTSA, with EPA, gathered information about these technologies for the 2012-2016 rulemaking from a wide variety of sources, discussed at length in the FRIA accompanying the 2012-2016 final rule. We refer readers to that document for more information.

Since the MY 2012-2016 final rule, EPA has contracted with Ricardo and expanded the technology selections available for the agencies' consideration, based on some of Ricardo's advanced engineering development work for EPA and on some recently-obtained literature sources, such as the development of Lotus Sabre[113] engine and MAHLE[114] engine. Based on this research, the agencies are considering significantly

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[112] Fuel cell vehicles may be especially useful in lieu of full battery electric technology for the larger trucks. We may consider this possibility for the final rule.

[113] Turner, J.W.G., R.J. Pearson, R. Curtis, and B. Holland, Lotus Engineering. "Sabre: a cost-effective engine technology combination for high efficiency, high performance and low CO_2 emissions." *Available at* http://www.midlandslotus.co.uk/forum/topic/35578-sabre-a-cost-effective-engine-technology-combination-for-high-efficie/ (last accessed Oct. 31, 2011).

[114] Frazer, N., H. Blaxhill, G. Lumsden, and M. Bassett, Mahle Powertrain. "Challenges for Increased Efficiency through Gasoline Engine Downsizing," SAE Paper 2009-01-1053. *Available at* http://papers.sae.org/2009-01-1053/ (last accessed Oct. 31, 2011).

more advanced gasoline engines for MYs 2017-2025 than we have considered for prior rulemakings. Ricardo also performed simulation analysis for EPA which the agencies have used to update the effectiveness for a majority of the technologies considered in this NPRM analysis. Detailed information for Ricardo's contract and body of work supporting this rulemaking can be found in Docket NHTSA-2010-0131.

For the reader's reference, the technologies considered by the NHTSA and EPA models for this NPRM are briefly described below. For purposes of how NHTSA applies them in our model, the technologies fit generally into five broad categories: engine, transmission, vehicle, electrification/accessory, and hybrid technologies. A more detailed description of each technology, and the costs and effectiveness of each, is described in greater detail below in this chapter; Chapter 3 of the draft joint TSD also contains information on the individual technologies. Types of engine technologies applied in the analysis for this NPRM that improve fuel economy include the following:

- *Low-friction lubricants (LUB1)* – low viscosity and advanced low friction lubricants oils are now available with improved performance and better lubrication.
- *Reduction of engine friction losses (EFR1)* – 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 (LUB2_EFR2)* – As technologies advance between now and 2017-2025, we expect further developments enabling lower viscosity and lower friction lubricants and more engine friction reduction technologies to be available.
- *Cylinder deactivation (DEACS and DEACD)* – 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 (CCPS, ICP and DCP)* – 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.
- *Discrete variable valve lift* (DVVLS, DVVLD and VVA) – 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 (CVVL)* – 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 (SGDI and SGDIO)* – 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 (TRBDS1 and TRBDS2)* - 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 NPRM, 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 both 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.[115]

- *Exhaust-gas recirculation boost (CEGR1 and CEGR2)* - 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 percent by volume in the highly boosted engines modeled by Ricardo (this, in turn raises the boost requirement by approximately 25 percent). This technology is only applied to 24 bar and 27 bar BMEP engines in this NPRM and considered required for 27 bar BMEP engines.
- *Diesel engines (ADSL)* – 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 NPRM analysis:

- *Improved automatic transmission controls (IATC)* – 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 (NAUTO)* – 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 (8SPD)* – 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.
- *High Efficiency Gearbox (automatic, DCT or manual) (HETRANS and HETRANSM)* – continuous improvement in seals, bearings and clutches, super

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[115] 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, November, 2011, Docket ID NHTSA-2010-0131

finishing[116] of gearbox parts, and development in the area of transmission lubrication, all aimed at reducing frictional and other parasitic load in the system for an automatic, DCT or manual type transmission.

- *Shift Optimization* (*SHFTOPT)* – tries to keep the engine operating near its most efficient point for a give power demand. The shift controller attempts to emulate a traditional CVT 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 (6MAN)* – offers an additional gear ratio, often with a higher overdrive gear ratio, than a 5-speed manual transmission.
- *High Efficiency Gearbox for manual transmission (HETRANSM)* – Similar technologies as applied for high efficiency gearbox for automatic and DCT can also be applied to manual transmissions to reduce drag in the system.

Types of vehicle technologies applied in this NPRM analysis:

- *Low-rolling-resistance tires (ROLL1 and ROLL2)* – have characteristics that reduce frictional losses associated with the energy dissipated in the deformation of the tires under load, therefore reducing the energy needed to move the vehicle. There are two levels of rolling resistance reduction considered in this NRPM analysis which assume 10 percent and 20 percent rolling resistance reduction, respectively. The agencies expect that tire manufacturers will be able to achieve widespread, production application of the 20 percent rolling resistance reduction level in time for MY 2017 and later.
- *Low-drag brakes (LDB)* – 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 (SAX)* – provides a torque distribution disconnect between front and rear axles when torque is not required for the non-driving axle, which reduces associated parasitic energy losses.
- *Aerodynamic drag reduction (AERO1 and AERO2)* – is achieved by changing vehicle shape or reducing frontal area, including skirts, air dams, underbody covers, and more aerodynamic side view mirrors. The new, second level of aerodynamic reductions involve employing aerodynamic aids which may include such features as active grille shutters, rear visors, larger under body panels or low-profile, and possibly dynamic, roof racks. There are two levels of aerodynamic drag reduction considered in this NPRM analysis which assume 10 percent and 20 percent drag reduction, respectively.
- *Mass reduction (MR1, MR2, MR3, MR4 and MR5)*– Mass reduction encompasses a variety of techniques to make vehicles lighter, ranging from improved design and better component integration to application of lighter and higher-strength materials. A lighter vehicle can go further on a gallon of gas, all else equal; mass reduction can also lead to collateral fuel economy benefits due to downsized engines and/or ancillary systems (transmission, steering, brakes, suspension, etc.).

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[116] "Super finishing" is a metalworking process that improves surface finish and workpiece geometry. Super finishing can make pieces more durable and allow for closer tolerances, higher load bearing surfaces, and better sealing capabilities, but it can also be more expensive than traditional metal finishing techniques.

The maximum mass reduction level considered in this NPRM for any vehicle is 20 percent.

Types of accessory/hybridization/electrification technologies applied in this NPRM analysis:

- *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 and only operates when needed, thereby reducing parasitic losses from the accessory drive.
- *Improved accessories (IACC1 and IACC2)* –There are two levels of IACC applied in this NPRM analysis. The first level of IACC includes an electric water pump and cooling fans and a high efficiency alternator; the second level of IACC includes some mild alternator regenerative braking in addition to what is included in the first level of IACC. This excludes other electrical accessories such as electric oil pumps and electrically driven air conditioner compressors.
- *Air Conditioner Systems* – For purposes of improvements in fuel economy that can count toward CAFE compliance, these technologies include improved compressors, expansion valves, heat exchangers and the control of these components for the purposes of improving fuel efficiency when the A/C is operating. These technologies are not modeled as part of the analysis for this NPRM, but NHTSA may include them in the modeling for the final rule. They are covered separately in Chapter 5 of the draft joint TSD.
- *12-volt Stop-Start (MHEV)* – 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.
- *P2 Hybrid (SHEV1 and SHEV2)* –a newly emerging hybrid technology that uses a transmission integrated electric motor placed between the engine and a gearbox or CVT, much like the IMA system described below except with a wet or dry separation clutch which is used to decouple the motor/transmission from the engine. Engaging the clutch allows all-electric operation and more efficient brake-energy recovery. Disengaging the clutch allows efficient coupling of the engine and electric motor and, when combined with a DCT transmission, reduces gear-train losses relative to power-split or 2-mode hybrid systems. In addition, a P2 Hybrid would typically be equipped with a larger electric machine, as compared to an IMA system.
- *Plug-in hybrid electric vehicles (PHEV1 and PHEV2)* – are hybrid electric vehicles with the means to charge their battery packs from an outside source of electricity (such as the electric grid), as well as a gasoline engine. These vehicles have larger battery packs 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.
- *Electric vehicles (EV1, EV2, EV3 and EV4)* – are vehicles with all-electric drive and with vehicle systems powered by energy-optimized batteries charged from

grid electricity and regenerative braking. EVs with 75 mile and 150 mile ranges have been included in the modeling for this NPRM and PRIA as potential technologies.

Types of accessory/hybridization/electrification technologies discussed but not applied in this NPRM analysis, for a variety of reasons, include:

- *Higher Voltage Stop-Start/Belt Integrated Starter Generator (BISG)* – sometimes referred to as a mild hybrid, BISG 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 motor, inverter, and battery wiring harnesses. This system replaces a standard alternator with an enhanced power, higher voltage, higher efficiency starter-alternator, that is belt driven and that can recover braking energy while the vehicle slows down (regenerative braking). This technology is not used as an enabling technology in this NPRM analysis because the agencies used the more cost effective P2 strong hybrid technology.
- *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, because the agencies applied the more cost effective P2 strong hybrid technology, although it is included as a baseline technology because it exists in the 2008 baseline fleet.
- *Power-split Hybrid (PSHEV)* – is a hybrid electric drive system that replaces the traditional transmission with a single planetary gearset and a motor/generator. This motor/generator uses the engine to either charge the battery or supply additional power to the drive motor. A 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. The power-split hybrid technology is not included as an enabling technology in this analysis, because the agencies applied the more cost effective P2 strong hybrid technology, although it is included as a baseline technology because it exists in the 2008 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 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, because the agencies applied the more cost

> effective P2 strong hybrid technology, although it is included as a baseline technology because it exists in the 2008 baseline fleet.

What does NHTSA then do with those technologies? We apply them to vehicles using the CAFE model.

As in the MYs 2012-2016 final rule, each technology is assigned to one of the five following categories based on the system it affects or impacts: engine, transmission, electrification/accessory, hybrid or vehicle. Each of these categories has its own decision tree that the CAFE model uses to apply technologies sequentially during the compliance analysis. The decision trees were designed and configured to allow the CAFE model to apply technologies in a cost-effective, logical order that also considers ease of implementation. For example, software or control logic changes are implemented before replacing a component or system with a completely redesigned one, which is typically a much more expensive option. In some cases, and as appropriate, the model may combine the sequential technologies shown on a decision tree and apply them simultaneously, effectively developing dynamic technology packages on an as-needed basis. For example, if compliance demands indicate, the model may elect to apply LUB, EFR, and ICP on a dual overhead cam engine, if they are not already present, in one single step.

For this NPRM analysis, the decision trees were updated to include additional technologies that the agency assumes will be available in the MYs 2017-2025 time frame. Each technology within the decision trees has an incremental cost and an incremental effectiveness estimate associated with it, and estimates are specific to a particular vehicle subclass. Each technology's incremental estimate takes into account its position in the decision tree path, which starts with the most cost-effective/simplest technology options at the top. If a technology is located further down the decision tree, the estimates for the costs and effectiveness values attributed to that technology are influenced by the incremental estimates of costs and effectiveness values for prior technology applications. In essence, this approach accounts for "in-path" effectiveness synergies, as well as cost effects that occur between the technologies in the same path. When comparing cost and effectiveness estimates from various sources and those provided by commenters, it is important that the estimates evaluated are analyzed by the agency in the proper context, especially as concerns their likely position in the decision trees and other technologies that may be present or missing. Not all estimates available in the public domain or offered for the agencies' consideration can be evaluated in an "apples-to-apples" comparison with those used by the CAFE model, since in some cases the order of application, or included technology content, is inconsistent with that assumed by NHTSA in the decision tree.

In the MY 2011 final rule, significant revisions had been made to the sequence of technology applications within the decision trees, and in some cases the paths themselves had been modified and additional paths had been added. These revisions were maintained for the MYs 2012-2016 final rule and this NRPM analysis. The additional paths allow for a more accurate application of technology, insofar as the model now considers the existing configuration of the vehicle when applying technology. In this analysis, single overhead camshaft (SOHC), dual overhead camshaft (DOHC) and overhead valve (OHV) configured engines have separate paths that allow for unique path-dependent versions of certain engine technologies. Thus, the cylinder deactivation technology (DEAC) now consists of three unique versions that depend on whether the engine being evaluated is an SOHC, DOHC or OHV design; these technologies are designated by the abbreviations DEACS, DEACD and DEACO, respectively, to designate which engine path they are located on. Similarly the last letter for the Coupled Cam Phasing (CCP) and Discrete Variable Valve Lift (DVVL) abbreviations are used to identify which path the technology is applicable to.

Use of separate valvetrain paths and unique path-dependent technology variations also ensures that the incremental cost and effectiveness estimates properly account for technology effects so as not to "double-count." For example, in the SOHC path, the incremental effectiveness estimate for DVVLS assumes that some pumping loss reductions have already been accomplished by the preceding technology, CCPS, which reduces or diminishes the effectiveness estimate for DVVLS because part of the efficiency gain associated with the reduction of the pumping loss mechanism has already occurred. This accounting approach resolves this potential double-counting issue.
In addition to incorporating new technologies for the MYs 2017-2025 time frame, the decision trees were also revised to include unique paths, based on engine displacement and cylinder configuration, for all turbocharged and downsized, cooled EGR, and diesel engines. This allows for more accurate accounting of incurred costs from the application of these advanced engine technologies. For each of these advanced engine technologies there are now three unique versions that depend on whether or not the engine is more similar to an inline 4-cylinder, a V6, or a V8 engine, and are defined by small displacement ("SD"), midsize displacement ("MD") and large displacement ("LD") designations, respectively. For example, the advanced diesel technology (ADSL) now consists of three unique versions that are designated by the abbreviations ADSL_SD, ADSL_MD and ADSL_LD.

To address any potential confusion, NHTSA would like to draw attention to the retention of previously applied technologies when more advanced technologies (*i.e.*, those further down the decision tree) were applied. For this proposal, as in previous rulemakings, , previously-applied technologies are retained in combination with the new technology being applied as appropriate and feasible, but not always. For instance, one exception to this would be the application of advanced diesel technology, where the entire engine is assumed to be replaced, so gasoline engine technologies do not (indeed, cannot) carry over. This exception for advanced diesels, along with a few other technologies, is documented below in the detailed discussion of each decision tree and corresponding technologies.

As the Volpe model steps through the decision trees and applies technologies, it accumulates total or "NET" cost and effectiveness values. Net costs are accumulated using an additive approach while net effectiveness estimates are accumulated multiplicatively. As with the MY 2012-2016 final rule, the decision trees have been expanded so that NHTSA is better able to track the incremental and net/cumulative cost and effectiveness of each technology, which substantially improves the "accounting" of costs and effectiveness for this NPRM.[117] To help readers better understand the accumulation process, and in response to comments expressing confusion on this subject, the following examples demonstrate how the Volpe model calculates net values. Accumulation of net cost is explained first, as this is the simpler process. This example uses the Transmission decision tree sequentially applying IATC, NAUTO, DCT, 8SPD, HETRANS, SHFTOPT technologies to a midsize passenger car using the cost and effectiveness estimates from its input sheet. As seen in Table V-5 below, for example, the net cost to apply all the transmission technologies would be ($61.88 + -$38.73 + -$73.88 + $255.18 + $248.38 + $1.65 = $454.48). Net costs are calculated in a similar manner for all the decision trees.

Table V-5. Example of Volpe Model Net Cost Calculation

<table>
<tr><th colspan="3">Example Net Cost (MY2017) Calculation:
Transmission Path, Midsize Vehicle Subclass</th></tr>
<tr><th>Tech. Abrev.</th><th>INCR Cost</th><th>NET Cost</th></tr>
<tr><td>IATC</td><td>$ 61</td><td>$ 61</td></tr>
<tr><td>NAUTO</td><td>$ (39)</td><td>$ 22</td></tr>
<tr><td>DCT</td><td>$ (74)</td><td>$ (52)</td></tr>
<tr><td>8SPD</td><td>$ 225</td><td>$ 173</td></tr>
<tr><td>HETRANS</td><td>$ 248</td><td>$ 421</td></tr>
<tr><td>SHFTOPT</td><td>$ 2</td><td>$ 423</td></tr>
</table>

The same decision tree, technologies, and vehicle are used for the example below which demonstrates the model's net effectiveness calculation. Table V-6 below shows average incremental effectiveness estimates in column two; this value is calculated in the same manner as the cost estimates above (average of lower and upper value taken from the input sheet). To calculate the change in fuel consumption due to application of the IATC technology with incremental effectiveness of 3.0 percent (or 0.030 in decimal form, column 3), when applied multiplicatively, means that the vehicle's current fuel consumption 'X' would be reduced by a factor of (1 – 0.030) = 0.970,[118] or mathematically 0.970*X. To represent the changed fuel consumption in the normal

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[117] In addition to the (simplified) decision trees, as published in this document, NHTSA also utilized "expanded" decision trees in this final rule analysis. Expanded decision trees graphically represent each unique path, considering the branch points available to the Volpe model, which can be utilized for applying fuel saving technologies. For instance, the engine decision tree shown in this document has 21 boxes representing engine technologies, whereas the expanded engine decision tree requires a total of 90 boxes to accurately represent all available application variants. Expanded decision trees presented a significant improvement in the overall assessment and tracking of applied technologies since they allowed NHTSA staff to accurately view and assess both the incremental and the accumulated, or net cost and effectiveness at any stage of technology application in a decision tree. Because of the large format of the expanded decision trees, they could not be included in the Federal Register, so NHTSA refers the reader to Docket No. NHTSA-2010-0131. Expanded decision trees for the engine, electrification/transmission/hybridization, and the vehicle technologies (three separate decision trees) were developed for each of the 12 vehicle technology application classes and have been placed in the docket for the reader's reference.

[118] A decrease in fuel consumption (FC) means the fuel economy (FE) will be increased since fuel consumption and economy are related by the equation FC = 1/FE.

fashion (as a percentage change), this value is subtracted from 1 (or 100%) to show the net effectiveness in column 5.

As the NAUTO technology is applied, the vehicle's fuel consumption is already reduced to 0.970 of its original value. Therefore the reduction for an additional incremental 2.04 percent results in a new fuel consumption value of 0.9502, or a net 4.98 percent effectiveness, as shown in the table. Net effectiveness is calculated in a similar manner for the all decision trees. All incremental effectiveness estimates were derived with this multiplicative approach in mind; calculating the net effectiveness using an additive approach will yield a different and incorrect net effectiveness.

Table V-6. Example of Volpe Model Net Effectiveness Calculation

Example Net Effectiveness Calculation: Transmission Path, Midsize Vehicle Subclass				
Tech. Abrev.	**INCR Eff. %**	**Eff. (decimal)**	**Multiplicative FC Reduction Current FC * (1- INCR)**	**NET Eff. (1-Red)**
IATC	3.00%	0.0300	1 * (1-0.03) = 0.970	3.00%
NAUTO	2.04%	0.0204	0.970 * (1 - 0.0204) = 0.9502	4.98%
DCT	4.06%	0.0406	0.9502 * (1 - 0.0406) = 0.9116	8.84%
8SPD	4.57%	0.0457	0.9116 * (1 - 0.0457) = 0.8700	13.00%
HETRANS	2.68%	0.0268	0.8700 * (1- 0.0268) = 0.8467	15.33%
SHFTOPT	4.08%	0.0408	0.8467 * (1 - 0.0408) = 0.8121	18.79%

To improve the accuracy of accumulating net cost and effectiveness estimates, "path-dependent corrections" were employed in the MYs 2012-2016 final rule and are being utilized in this proposal. The previous 2008 analysis for the MYs 2011-2015 NPRM had the potential to either overestimate or underestimate net cost and effectiveness depending on which decision tree path the Volpe model followed when applying the technologies. For example, if in the 2008 NPRM analysis a diesel technology was applied to a vehicle that followed the OHV path, the net cost and effectiveness could be different from the net estimates for a vehicle that followed the OHC path, even though the intention was to have the same net cost and effectiveness. In order to account for this, "in path"-dependent correction tables were added to the input sheets. The model uses path-dependent correction factors, found in the synergy tables of the technology input sheets, to correct net cost and effectiveness estimate differences that occur when multiple paths lead into a single technology that is intended to have the same net cost and effectiveness no matter which path was followed. Path-dependent corrections were used when applying cylinder deactivation (on the DOHC path) and turbocharging and downsizing. For the cylinder deactivation the fuel consumption reduction and cost estimates stated in the following sections and the input sheets are for an engine with DVVL. The above-mentioned correction factors are then used to adjust the estimates for an engine with CVVL.

Similarly, the fuel consumption reduction and cost estimates stated in following sections and the input sheets for turbocharging and downsizing are for an SOHC engine. Correction factors are then used to adjust the estimates for the different paths (*i.e.*, DOHC or OHV).

What's new in this rulemaking?

Since the MY 2012-2016 final rule, additional analyses and studies have been initiated to improve the technology cost and effectiveness estimates used as inputs for this and future CAFE rulemakings. Some of these analyses and studies have been completed already, and their results were available for use in this NPRM analysis. The following sections briefly describe some of the new inputs that NHTSA and EPA have incorporated for this analysis.

More Vehicle Technologies (LUB2-EFR2, Higher BMEP Engine, P2, Level II of Tire Rolling Resistance, Level II of Aerodynamic Drag Reduction)

The agencies have applied several new technologies and also included a new additional level of effectiveness for several technologies in this NPRM analysis. The agencies are employing an additional level of engine friction reduction (representing engine friction reductions of 20 percent, compared to the 10 percent reductions previously assumed), an additional level of aerodynamic drag reduction (representing drag reductions of 20 percent), and an additional level of tire rolling resistance reduction (representing a rolling resistance reduction of 20 percent).

Other changes to the technologies employed in the modeling include, based on Ricardo's work for EPA, the addition of higher BMEP engines than considered in prior rulemaking analyses, such as 24 bar and 27 bar BMEP engines; and two additional technology options which have been added to the transmission decision tree, high efficiency gearbox and shift optimization. The strong hybrid technologies used in the MYs 2012-2016 final rule, power split and 2-mode hybrid, have been replaced in this NPRM analysis by P2 hybrid, which is applied instead of the other two technologies due to its lower cost and higher effectiveness. Transmission technologies are revised significantly as well, insofar as the "6-, 7- and 8- speed transmission" group is now divided into two groups, a "6-speed transmission" group and an "8-speed transmission" group, based on information gathered by the agencies. All of these changes reflect the agencies' expectation for technology development before and during MYs 2017-2025 timeframe. The agencies believe that these technologies will provide a cost effective path in reducing fuel consumption and GHGs.

Updated Effectiveness Estimates

EPA contracted with Ricardo Engineering to provide vehicle simulation support for this proposal. This simulation work provided basis for the effectiveness estimates for a number of the technologies most heavily relied on in the agencies' analysis of potential standards for MYs 2017-2025. Some of technology effectiveness values that were informed by the 2010/2011 Ricardo study were advanced engine friction reductions, higher BMEP engines, advanced transmissions, start-stop systems and P2 hybrids. More information about the Ricardo work is available in TSD Chapter 3 or Docket NHTSA-2010-0131.

More Costs from FEV Teardown Study

Since the MYs 2012-2016 final rule, FEV, contracted by EPA, has completed two more tear-down studies that the agencies used for this NPRM analysis: a tear-down study comparing the cost of an 8-speed automatic transmission to a 6-speed automatic transmission, and a tear-down study of a power-split hybrid to determine the incremental costs of converting a conventional gasoline powered vehicle (a V6 Ford Fusion) to a power-split hybrid (a Ford Fusion hybrid). The results for individual components in power-split hybrid teardown were subsequently used to cost another hybrid technology, the P2 hybrid, which employs similar hardware.

Updates for the Cost of HEV, PHEV, EV

The agencies have reconsidered the costs for HEVs, PHEVs, EVs, and FCEVs as the result of two issues. First, electrified vehicle technologies are developing rapidly: different battery materials and different hybrid systems are proliferating, and battery costs are coming down. And second, the analysis for the MYs 2012-2016 final rule employed a single $/kWhr estimate, and did not consider the specific vehicle and technology application for the battery when we estimated the cost of the battery.[119] 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 differences in cost per kW-hr as the power to energy ratio of the battery changes for different applications. To address these issues for this proposal, the agencies have used a battery cost model, BatPac,[120] developed by Argonne National Laboratory (ANL) for the Vehicle Technologies Program of the U.S. Department of Energy's (DoE) Office of Energy Efficiency and Renewable Energy. The model developed by ANL allows users to estimate unique battery pack cost using user-customized input sets for different hybridization applications, 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 many suggestions from peer-reviewers. EPA staff used this newly updated model to derive battery costs for this NPRM analysis, and we discuss our updated battery costs in section in Section 0. The agencies added new configurations of HEV, PHEV and EV vehicles to the ANL model for this NPRM analysis that include the P2 HEV configuration, different mileage ranges for PHEVs and different mileage ranges for EVs. Details regarding these vehicle technologies are discussed in section 0.

Updates for the Cost of Mass Reduction and Level of Mass Reduction

The cost of mass reduction has been updated since to the MYs 2012-2016 final rule. In the last rulemaking, a constant cost of $1.32/lb was used. In this NPRM analysis, a linear cost curve is used at a rate of $4.29/lb/percent of mass reduction. Additionally, the amount of mass reduction considered by the agencies as available for purposes of this

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[119] 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.

[120] BatPac Model and peer-review report are in docket NHTSA-2010-0131.

analysis is generally increased. The maximum amount of mass reduction applied to vehicles in NHTSA's analysis is 20 percent, although varying amounts are applied to different types of vehicles in order to ensure that a safety neutral path is developed: specifically, less mass reduction is applied to smaller vehicles, such as compact cars, and more is allowed to be applied to larger vehicles, such as large pickup trucks and SUVs. The mass reduction section below contains detailed descriptions for mass reduction costs, available technologies and the agencies' work plan for refining these estimates for the final rule.

Modification of ICM

For the analysis in this NPRM, NHTSA and EPA have revisited the technologies evaluated by EPA staff and relied primarily on the modified Delphi based technologies develop the ICMs. For this NPRM analysis, the agencies are using the following basis for estimating ICMs:

- All low complexity technologies will be estimated to equal the ICM of the modified Delphi based low technology - passive aerodynamic improvements.
- All medium complexity technologies will be estimated to equal the ICM of the modified Delphi based medium technology - engine turbo downsizing.
- Strong hybrids and non-battery PHEVs will be estimated to equal the ICM of the high complexity consensus based high technology – hybrid electric vehicle.
- PHEVs with battery packs and full electric vehicles will be estimated to equal the ICM of the high complexity modified Delphi based high technology – plug-in hybrid electric vehicle.

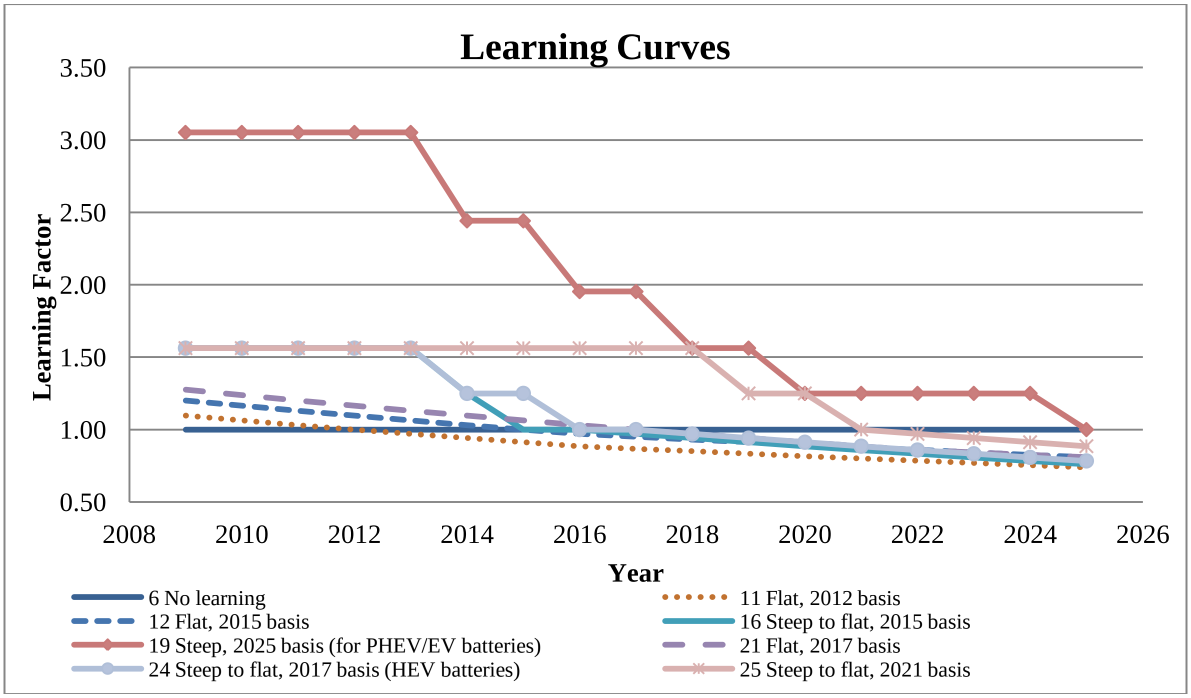
In addition to shifting the proxy basis for each technology group, the agencies reexamined each technology's complexity designation and adjusted the grouping of technologies. Some new technologies are also added to the groupings. Other changes to the ICMs for this rulemaking include basing them on the expected long-term average RPE rather than that of any one specific year (2007), which involved normalizing them to an average RPE multiplier level of 1.5; and distinguishing the ICMs into two parts, one applied to warranty cost and one applied to non-warranty cost. The latter was done because the agencies believe that learning curves are more appropriately applied only to direct costs, with indirect costs established up front based on the ICM and then held constant while direct costs are reduced by learning.

More detailed information about how the agencies applied ICMs in this NPRM analysis can be found in Chapter VII of this PRIA.

More and Refined Learning Schedules

In MYs 2012-2016 rulemaking, the agency applied two types of learning, "time-based" learning and "volume-based" learning. For this NPRM the agency has, however, adopted new terminology to distinguish the two different learning applications. Emerging technologies are adjusted using what we now call the "steep "learning schedule, which involves 20% decreases, while mature technologies are modified using one of a number of "flat" schedules, involving the smaller 3%, 2%, or 1% decreases. The "flat" curves assume a learning rate of 3% over the previous years' cost for a number of years, followed by 2% over several more years, followed by 1% indefinitely. The "steep" curves assume larger decreases of 20% every 2 years during the initial years of production, for a maximum of two learning cycles, before converting to the "flat" learning curve rates. For this NPRM analysis, the agency has determined where on the learning curve each technology lies and then applied learning effects based on those determinations. Figure V-11 shows how these determinations impact the level of learning effects applied in our analysis.. Chapter VII of this PRIA contains a detailed discussion of the changes to the ICM and their application to individual technologies.

Figure V-11. Learning Factors used in the Analysis to accommodate Technologies at Different Places on the Learning Curve and Having Costs Based in Different Years



Inclusion of Stranded Capital Costs

There is also the potential for stranded capital[121] if technologies are introduced too rapidly for some indirect costs to be fully recovered. Due to the capital-intensive nature of producing automotive components, it is possible for substantial capital investments in manufacturing equipment and facilities to become "stranded". While the FEV tear-down analysis results are assumed to be generally valid for the 2017-2025 timeframe for fully mature, high sales volumes, FEV perform a supplemental analysis to consider potential

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[121] The potential for stranded capital occurs when manufacturing equipment and facilities cannot be used in the production of a new technology.

stranded capital costs. For a select group of technologies NHTSA has included that ability account for stranded capital costs, as supplied by FEV, into the analysis. The agency refers readers to Chapter 3 of the draft joint TSD for a more detailed description of how FEV estimated stranded capital costs and later in this chapter the agency describes how stranded capital costs were integrated into the analysis.

How are technologies applied in the CAFE model?

As discussed above, the Volpe model uses decision trees to determine the order in which technologies are applied to each vehicle in our analysis. The following paragraphs explain, in greater detail, the decision tree logic and revisions to the decision trees from the MY 2012-2016 final rule that have been incorporated for this NPRM.

Engine Technology Decision Tree

For this NPRM, NHTSA modified the engine decision tree and the model's technology application logic that was employed in the MYs 2012-2016 final rule by revising some of the paths and adding new technologies that the agencies assume will be available in the MYs 2017-2025 timeframe. Figure V-12 below shows a simplified decision tree for the engine technology category.

As was the case in the MYs 2012-2016 final rule, SOHC, DOHC and OHV engines continue to have separate paths to allow the model to apply unique path-dependent valvetrain technologies (Variable Valve Timing, Variable Valve Lift, and cylinder deactivation) that are tailored to those specific engine types. These path-dependent valvetrain technologies are designated by the letter "S" for SOHC, "D" for DOHC and "O" for OHV at the end of each technologies acronym. From example, cylinder deactivation (DEAC) on the SOHC is designated as DEACS. This approach also improves the accuracy of our accounting for net cost and effectiveness, because the unique cost and effectiveness estimates for each engine type can account for the fact that SOHC engines only have one camshaft per bank of cylinders, DOHC engines have two camshafts per bank of cylinders and OHV engines only have one camshaft regardless of whether or not the engine is an inline or V configuration.

A number of changes have been made to the engine decision tree for the MYs 2017-2025 analysis in order to reflect changes in our technology assumptions for this rulemaking as compared to the MYs 2012-2016 final rule. As explained above, a second step of low-friction lubricants and engine friction (LUB2_EFR2) is included in the agencies' analysis and has thus been added to the decision tree, as a single technology following EFR1. On the OHV path, coupled cam phasing (CCP) and discrete variable valve lift (DVVL) have been combined into one technology, variable valve actuation (VVA). This was done because, and as discussed below, cylinder deactivation (DEAC), which utilizes lost motion devices that enable DVVL operation, precedes both CCP and DVVL so when applying CCP it seems logical to apply DVVL, at no cost due to being enabled by DEAC, to utilize the additional valve control the conversion to DOHC has been deleted from the OHV path based on the assumption that manufacturers are more likely to proceed to a turbocharged and downsized engine, which has a higher potential for fuel consumption reductions, rather than to a naturally aspirated DOHC engine in the event that they need to replace the existing OHV engine Additionally, the OHV path now has its own unique stoichiometric gasoline direct injection technology (SGDIO).

The combustion restart (CBRST) technology has been deleted as an enabling engine technology based on the assumption that it is likely that manufacturers will accomplish stop-start functionality by way of a 12V integrated starter/generator (MHEV).
The turbocharging and downsizing and cooled EGR technologies are considered to be a completely new engines that have been converted to DOHC (if not already a DOHC in the baseline vehicle) with LUB, EFR, LUB2_EFR2 (post MY 2016) DCP and SGDI applied. For this proposal, the agency has added a second step of turbocharging and downsizing (TRBDS2) with a higher Brake Mean Effective Pressure (BMEP[122]) level. The EGR Boost technology from the MYs 2012-2016 technology has been renamed to cooled EGR (CEGR1 and CEGR2) and has been expanded to include two steps with the second utilizing higher BMEP levels. For this analysis, the conversion to Diesel is now only one technology following CEGR2, and has been renamed advanced diesel (ADSL) Similar to the turbocharged and downsized engines, ADSL is considered to be a completely new engine that replaces the gasoline engine (although it carries over the LUB, EFR and LUB2_EFR2 technologies, which are assumed to still be applicable to diesels). We note that because in the TRBDS1 all engines are converted to DOHC engines; there are not path-dependent variations of the TRBDS2, CEGR1, CEGR2 and ADSL technologies, which means that the same technology state is reached by the modified vehicle regardless of the path the model followed to achieve it. Therefore, in conducting the analysis, the *net* cost and effectiveness estimates for the different engine paths are considered to be the same (regardless of path), and the *incremental* cost and effectiveness estimates are adjusted as appropriate to account for the path-dependent variations.

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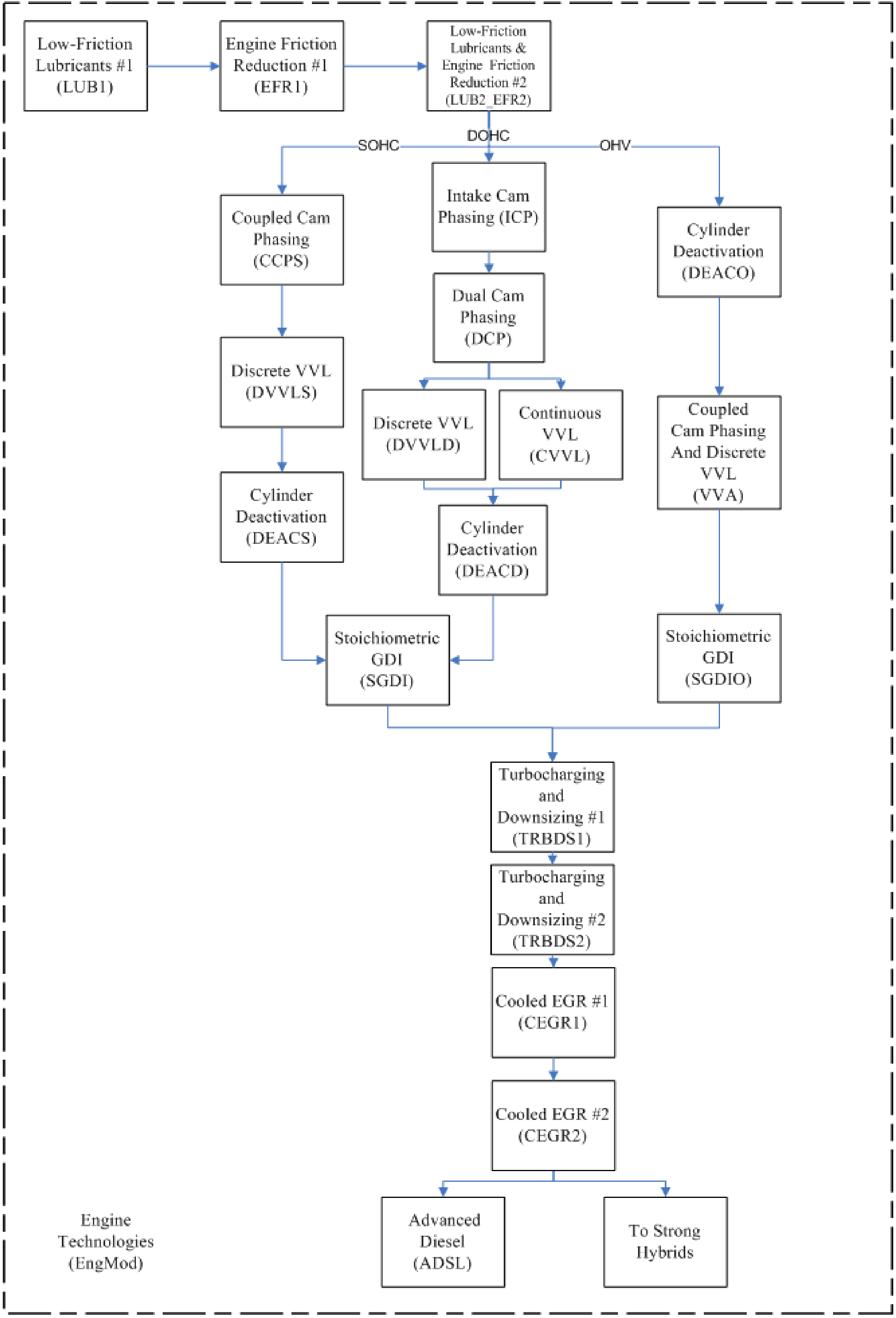
[122] BMEP refers to brake mean effective pressure, a common engineering metric which describes the specific torque of an engine, as a way of comparing engines of different sizes. It is usually expressed in units of bar, or kPa. Current naturally aspirated production engines typically average 10-12 bar 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 equivalent sized engine that achieves 10 bar BMEP.

Figure V-12. Engine Technology (EngMod) Decision Tree



Electrification/Accessory Technology Decision Tree

After reviewing this decision tree, NHTSA made some revisions from the version used in the MYs 2012-2016 final rule. Specifically, since the agencies are considering a second level of Improved Accessories (IACC) after the first level to consider technologies such as mild levels of alternator regenerative braking, the decision tree was modified to include that additional technology option. Belt Mounted Integrated Starter Generator (BISG) and Crank Mounted ISG (CISG) are now combined into one technology, Integrated Starter Generator (ISG). Even though ISG is not used in this analysis, this technology acts a placeholder in the decision tree for the possibility of including a mild hybrid technology in the final rule analysis. The updated decision tree is shown in Figure V-14.

Electric Power Steering (EPS) is the first technology in this decision tree, since it is a primary enabler for stop-start systems and mild and strong hybrids, and is followed by the first level of Improved Accessories (IACC1), as in the MY 2012-2016 final rule. IACC1 is then followed by a second level of improved accessory (IACC2), which includes a mild level of regenerative braking, as stated above. Micro-Hybrid (MHEV), a 12-volt system that offers basic idle stop/start functionality only, follows IACC2. An ISG technology block is placed on the decision tree, again, to represent the higher voltage system with stop/start and higher level of energy recovery through regenerative braking. All Electrification/Accessory technologies can be applied to both automatic and manual transmission vehicles.

Transmission Technology Decision Tree

For this NPRM, NHTSA reviewed the transmission technology decision tree and the model’s technology application logic used in the MYs 2012-2016 final rule, and made some revisions. This decision tree, shown in Figure V-14, contains two paths: one for automatic/dual clutch transmissions and one for manual transmissions. The CVT path used in MYs 2012-2016 final rule has been removed due to the assumed low market penetration of CVTs in the U.S. in the rulemaking timeframe.

On the automatic/dual clutch path, the decision tree first optimizes the current transmission by improving the control system via the Improved Automatic Transmissions Controls and other Externals (IATC) technology. After IATC, the decision tree moves to 6-speed automatic transmission with improved internals (NAUTO). The NAUTO technology is followed by the 6-speed Dual Clutch Transmission (DCT) technology. Dual Clutch Transmission (DCT) designs do not suffer torque interrupt when shifting; a characteristic associated with automated manual transmission (AMT) designs. In response to comments from manufacturers expressing concern that torque interrupt will not be acceptable to consumers, AMT designs are not included in this analysis. The DCT technology is disabled for vehicles with towing requirements, such as Midsize Light Truck (LT), Large LT and Minivan LT vehicle subclasses. After DCT, the decision tree progresses to an 8-speed transmission (8SPD). For vehicles with towing requirements, the 8SPD technology represents an 8-speed automatic. However, for all other vehicles the 8SPD technology represents a transition to an 8-speed DCT from a 6-speed DCT.

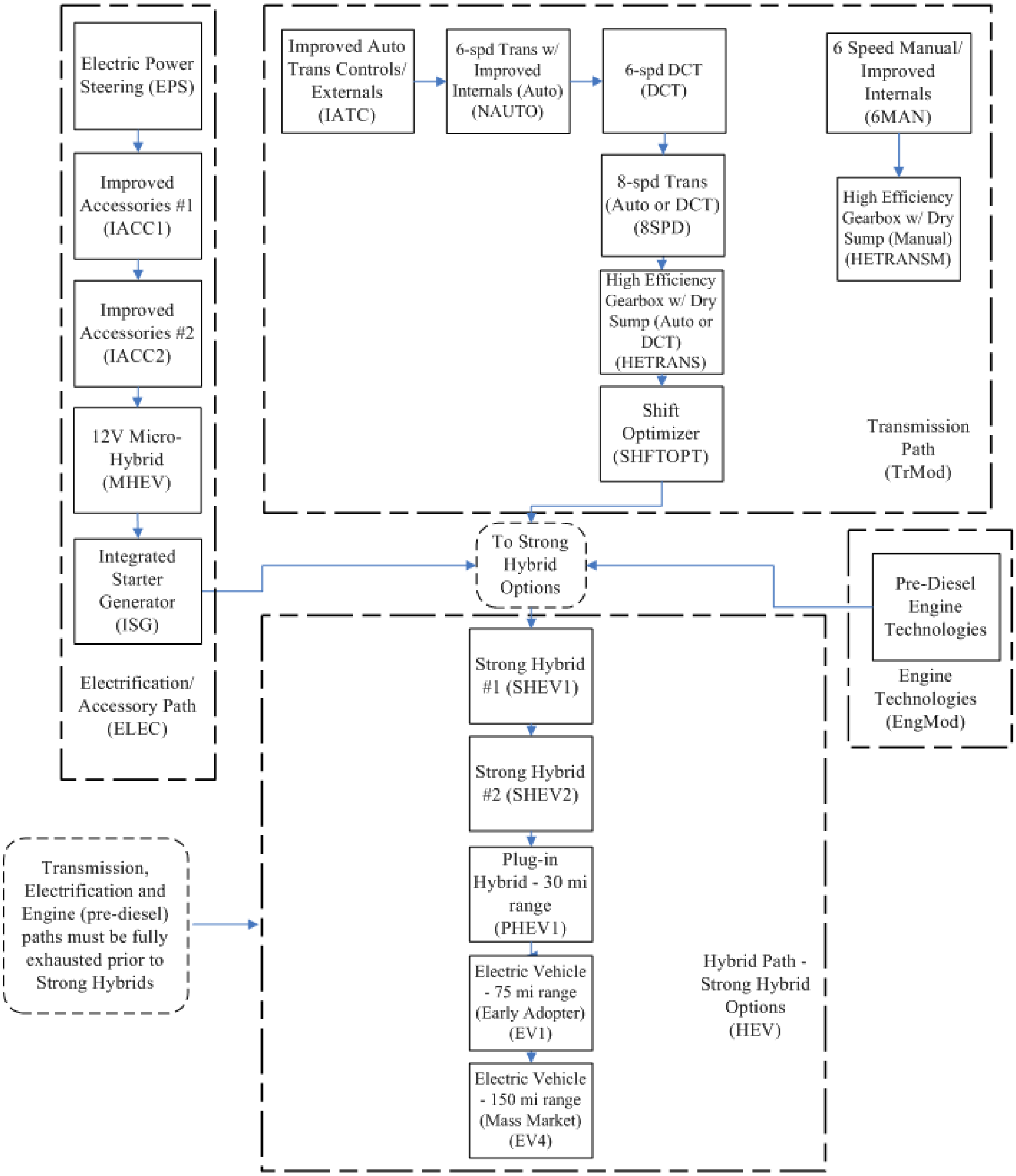
Following the 8SPD technology are two new technologies added for this NPRM: high efficiency gear box (HETRANS) and shift optimization (SHFTOPT). Each of these technologies can be applied to both DCT and automatic transmissions.

As in the 2012-2016 final rule analysis, the manual transmission path has only two technology applications: conversion to a 6-Speed Manual with Improved Internals (6MAN), and high efficiency gearbox (HETRANSM). NHTSA anticipates limited use of manual transmissions with more than 6 speeds within the MYs 2017-2025 timeframe.

Hybrid Technology Decision Tree

NHTSA also reviewed the hybrid technology decision tree and the model's technology application logic used in the MY 2012-2016 final rule, and made revisions to this decision tree anticipating that more HEV, PHEV and EV vehicles will penetrate the market for the MYs 2017-2025 rulemaking period. The model continues to apply only strong hybrid technologies when both the Electrification/Accessory and Transmission (automatic/dual clutch transmissions only) technologies have been fully added to the vehicle, as seen in Figure V-14. When the CAFE model applies strong hybrids, it accounts for the fact that some of the fuel consumption reductions have already been included when technologies like EPS or IACC have been previously applied. The decision tree contains two levels of strong hybrid technologies: SHEV1 and SHEV2. SHEV1 is applied when defining the MYs 2012-2016 baseline and SHEV2 is applied in the MYs 2017-2025 analysis. SHEV2 represents a second generation of strong hybrids that includes advances in engine and transmission technologies assumed to be available in MYs 2017-2025. The model's logic will allow a vehicle with the SHEV1 technology, either as applied by the model or present in the baseline, to be converted to SHEV2 in the MYs 2017-2025 timeframe. After SHEV2, the decision tree advances to a 30-mile range plug-in hybrid (PHEV1). Should the need arise in the final rule to incorporate another PHEV technology with a different range, a placeholder technology, PHEV2, has been added to the decision tree. Following SHEV2 in the decision tree are four electric vehicle (EV) technologies: EV1, EV2, EV3 and EV4. EV1 is a 75-mile range EV assumed to be marketed to early adopters of the EV technology. EV2 and EV3 are not used in this analysis and are reserved for adding different versions of EVs with different ranges. EV4 represents a 150-mile range EV that is assumed to be marketed as a mass market vehicle.

Figure V-13. Electrification/Accessory, Transmission and Hybrid Technology Decision Tree



Vehicle Technology Decision Tree

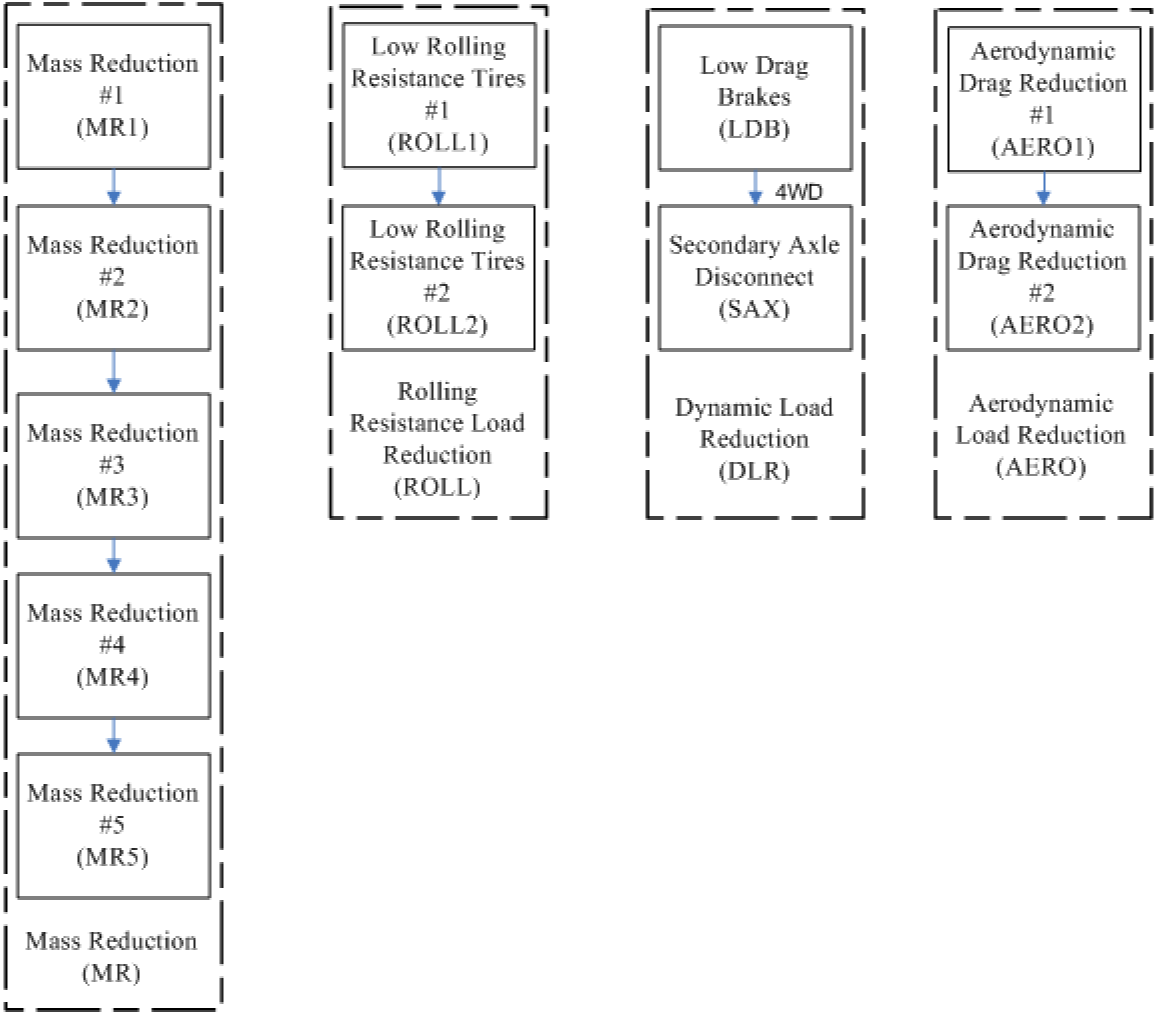
After reviewing this decision tree, NHTSA made some revisions to the vehicle technology tree from the version used in the MYs 2012-2016 final rule. The MY 2012-2016 final rule utilized three Material Substitution (MS) technologies in a dedicated path in the Vehicle Technology Decision tree. For this NPRM, Material Substitution has been renamed Mass Reduction (MR) and has been expanded to five levels as shown in Figure V-15. All have a different definition (in terms of the amount of mass reduction that they can represent) than was used in the prior rule, and the definition for the level of mass reduction differs with each vehicle subclass. For example, only MR1 and MR2 are used for midsize passenger cars representing a total of mass reduction of 5 percent, while MR1 to MR5 are used for large pickup trucks representing a total mass reduction of 20 percent. Section 0 contains detailed description of how mass reductions are applied in this analysis.

Low Drag Brakes (LDB) and Secondary Axle Disconnect (SAX) have the same definition and path as used in the MYs 2012-2016 final rule, with SAX still applied to 4WD vehicles only.

Low Rolling Resistance Tires (ROLL) is separated from LDB and SAX path. There are 3 levels of Low Rolling Resistance Tire in the decision tree, ROLL1, ROLL2 and ROLL3. However, only ROLL1 and ROLL2 are used in this NPRM; the third level is reserved for potential future use.

Aerodynamic Drag Reduction also remains a separate path and there are now two levels of aerodynamic drag reduction in this NPRM analysis, AERO1 and AERO2. The MYs 2012-2016 final rule only had one level of AERO.

Figure V-14. Vehicle Technology Decision Tree



Is this model year an appropriate time to add the technology? (year of availability; refresh and redesign schedule)

Manufacturers typically plan vehicle changes to coincide with certain stages of a vehicle's life cycle that are appropriate for the change, or in this case the technology being applied. 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 vehicle platform. 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.

There are many factors that can affect when or how often redesigns occur, such as availability of capital and engineering resources and the extent of platform and component sharing between vehicle models, or even between manufacturers, if cooperation is involved. Historically high-volume cars have followed roughly a 5-year redesign cycle to remain competitive in the market. On the other hand, a few of the niche market or small-volume manufacturer vehicles (*i.e.* luxury and performance vehicles), as well as large trucks and full size vans, have historically followed longer 6- to 8-year redesign cycles. Managing product lines and refresh and redesign cycles is a complex task undertaken by manufacturers to respond to consumer preference trends and to comply with regulations in the most cost- and resource-effective way possible. The agency believes that manufacturers can and will accomplish much improvement in fuel economy and GHG reductions while applying technology consistent with their redesign schedules. While manufacturers look to make common design and technology changes across a vehicle platform, consumer preference trends and regulation can sometimes require manufacturers to use flexibilities such vehicle-specific designs and technology changes in addition to broader vehicle platform level changes at refresh/redesign times in order to stay competitive and ensure compliance. As fuel economy standards become more stringent over time, NHTSA believes that manufacturers will use every opportunity to improve the fuel economy performance of their vehicles.

For the majority of technologies discussed in this proposal, 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.[123] Some technologies (*e.g.*, those that require significant revision) are nearly always applied only when the vehicle is expected to be redesigned, like turbocharging and engine downsizing, or conversion to diesel or hybridization. Other technologies, like cylinder deactivation, electric power steering, and low rolling resistance tires can be applied either when the vehicle is expected to be refreshed or when it is expected to be redesigned, while low friction lubricants, can be applied at any time, regardless of whether a refresh or redesign event is conducted. Accordingly, the model will only apply a technology at the particular point deemed suitable. These constraints are intended to produce results consistent with how we assume manufacturers will apply technologies in the future based on how they have historically implemented new technologies. For each technology under consideration, NHTSA specifies whether it can be applied any time, at refresh/redesign, or only at redesign. The data forms another input to the Volpe model.

For this proposal, NHTSA developed redesign and refresh schedules for each of a manufacturer's vehicles included in the analysis, essentially based on the last known redesign year for each vehicle, and projected forward using a 4 to 8-year redesign and a 2–3 year refresh cycle. NHTSA used publicly-available data to estimate the last known

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[123] For example, applying material substitution through weight reduction, or even something as simple as low rolling-resistance tires, to a vehicle will likely require some level of validation and testing to ensure that the vehicle may continue to be certified as compliant with NHTSA's Federal Motor Vehicle Safety Standards (FMVSS). Weight reduction might affect a vehicle's crashworthiness; low rolling-resistance tires might change a vehicle's braking characteristics or how it performs in crash avoidance tests.

redesign schedule for the vehicles produced by the manufacturers.[124] The agency also used this public data along with engineering judgment to estimate the number of years between redesigns to develop the unique redesign schedules for each vehicle model in the analysis. Thus, if a vehicle was last redesigned in MY 2008 and is assumed to have 6 years between redesigns, the redesign cycle will be as follows: MY 2008, MY 2014, and MY 2020. The refresh schedules were determined in a similar fashion, based on those of the baseline fleet and using the 2 to 3 year cycle assumption. NHTSA believes that this approach is reasonable given the nature of the current baseline, which as a single year (MY 2008) of CAFE certification data, as discussed in Chapter III above, does not contain its own refresh and redesign cycle cues for future model years. This approach also helps to ensure the complete transparency of the agency's analysis.[125] For the final rule NHTSA intends to update the baseline fleet, hopefully using the more current MY 2010 CAFE certification data in lieu of the MY 2008 certification data, and the agency will reassess vehicle redesign schedules as part of this update. The agency seeks comment on the approach taken to estimate vehicle redesign schedules and on the schedules themselves.

We note that this approach taken for this proposal is different from what NHTSA has employed previously for determining redesign and refresh schedules. For the MYs 2012-2016 final rule, NHTSA assumed that passenger cars would normally be redesigned every 5 years, consistent with industry trends over the last 10-15 years, unless a manufacturer had submitted product plans indicating that they expected to pursue a more rapid redesign and refresh schedule.[126] In the MYs 2012-2016 final rule, NHTSA also projected a 5-year redesign cycle for the majority of light trucks.[127] In the MY 2011 final

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[124] Sources included, but were not limited to, manufacturers' web sites, industry trade publications (*e.g.*, Automotive News), and commercial data sources (*e.g.*, Ward's Automotive, etc.).

[125] While the greater transparency of using historical certification data is an undeniable benefit, using adjusted historical data rather than estimated future data also impacts how NHTSA is able to model the refresh/redesign cycle in its analysis of year-by-year maximum feasible CAFE standards. For example, manufacturers have indicated (either publicly or in their product plans) that some vehicles that exist in the MY 2008 certification-data based fleet will be discontinued (*i.e.*, no longer produced or sold) prior to or within the rulemaking period. Conversely, some vehicle models have already been or will be introduced to the market during the rulemaking time frame, like GM's Chevy Volt and Chrysler's anticipated new models based on Fiat platforms. Since these vehicles were not sold in 2008, they do not exist in the MY 2008 certification data, and thus do not exist in the model's market data file for this NPRM analysis. To address this problem, the agency assumes that future vehicles are replacements for vehicles currently in the market and will tend to follow the same cycles as their predecessors, so it is appropriate to reflect the same redesign cycle in the market data file.

NHTSA believes that it is reasonable to expect that the manufacturer will produce a similar vehicle, or some group of similar vehicles, to compete in the same market segment—whether the manufacturer will offer the same vehicle model, a fully redesigned but otherwise similar version of that model, or an entirely new vehicle or group of vehicles, sold as a new model or nameplate of a similar type. This is how NHTSA addresses the issue of the GM Volt: although it does not appear in the baseline market data file, it will be considered as one of the existing GM models of similar type and in the same market segment once it becomes available.

[126] Exceptions were made for high performance vehicles and other vehicles that traditionally had longer than average design cycles due to their unique design characteristics and their evolutionary, as opposed to revolutionary product development practices (*e.g.*, the Porsche 911 has remained the same basic vehicle for many years).

127 NHTSA recognized in the MY 2011 CAFE rulemaking that light trucks are currently redesigned every 5 to 7 years, with some vehicles (like full-size vans) having longer redesign periods. However, in the most

rule, NHTSA reviewed manufacturers' planned redesign and refresh schedules as stated in their confidential submissions and incorporated them into the market data file, or relied on other sources of information where that data did not exist.

Even within the context of the phase-in caps discussed below, NHTSA considers these model-by-model scheduling constraints of refresh and redesign schedules necessary in order to produce an analysis that reasonably accounts for the need for a period of stability following the redesign of any given vehicle model. If engineering, tooling, testing, and other redesign-related resources were unlimited, every vehicle model could be redesigned every year. In reality, however, every vehicle redesign consumes resources simply to address the redesign, and thus cost expenditures occur. Phase-in caps, which are applied at the level of a manufacturer's entire fleet, do not, by themselves, constrain the scheduling of changes to any particular vehicle model. Conversely, scheduling constraints to address vehicle freshening and redesign do not necessarily yield realistic overall penetration rates for a particular technology type (*e.g.*, for strong hybrids), while phase-in caps do. Thus, the two constraints work together in the model to ensure that the timing and application rate for various fuel-saving technologies is feasible for manufacturers on a year-by-year basis, as required by EPCA/EISA.[128]
The baseline market data file, available on NHTSA's website, contains the refresh and redesign dates developed by NHTSA for this proposal. Table V-7 below provides whether particular technologies are "anytime" technologies, "redesign only" technologies, or "refresh or redesign" technologies, for purposes of this final rule.

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competitive SUV and crossover vehicle segments, the redesign cycle currently averages slightly above 5 years. NHTSA concluded that the light truck redesign schedule will be shortened in the future due to competitive market forces. Thus, for almost all light trucks scheduled for a redesign in the early portions of the rulemaking period, NHTSA projected a 5-year redesign cycle.

[128] 49 U.S.C. § 32902(a) requires that NHTSA set CAFE standards at the maximum feasible level for each fleet, for each model year.

Table V-7. Technology Refresh and Redesign Application

Technology	Abbr.	Redesign Only	Redesign or Refresh	Anytime
Low Friction Lubricants - Level 1	LUB1			X
Engine Friction Reduction - Level 1	EFR1		X	
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2		X	
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS		X	
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	X		
Cylinder Deactivation on SOHC	DEACS		X	
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP		X	
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP		X	
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	X		
Continuously Variable Valve Lift (CVVL)	CVVL	X		
Cylinder Deactivation on DOHC	DEACD		X	
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	X		
Cylinder Deactivation on OHV	DEACO		X	
Variable Valve Actuation - CCP and DVVL on OHV	VVA	X		
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	X		
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	TRBDS1_SD	X		
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	TRBDS1_MD	X		
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	TRBDS1_LD	X		
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	TRBDS2_SD	X		
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	TRBDS2_MD	X		
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	TRBDS2_LD	X		
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	X		
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	X		
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	X		
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	X		
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	X		
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	X		
Advanced Diesel - Small Displacement	ADSL_SD	X		
Advanced Diesel - Medium Displacement	ADSL_MD	X		
Advanced Diesel - Large Displacement	ADSL_LD	X		
6-Speed Manual/Improved Internals	6MAN	X		
High Efficiency Gearbox (Manual)	HETRANSM	X		
Improved Auto. Trans. Controls/Externals	IATC		X	
6-Speed Trans with Improved Internals (Auto)	NAUTO	X		
6-speed DCT	DCT	X		
8-Speed Trans (Auto or DCT)	8SPD	X		
High Efficiency Gearbox (Auto or DCT)	HETRANS	X		
Shift Optimizer	SHFTOPT		X	
Electric Power Steering	EPS		X	
Improved Accessories - Level 1	IACC1		X	
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	IACC2		X	
12V Micro-Hybrid (Stop-Start)	MHEV	X		
Integrated Starter Generator	ISG	X		
Strong Hybrid - Level 1	SHEV1	X		
Conversion from SHEV1 to SHEV2	SHEV1_2	X		
Strong Hybrid - Level 2	SHEV2	X		
Plug-in Hybrid - 30 mi range	PHEV1	X		
Plug-in Hybrid	PHEV2	X		
Electric Vehicle (Early Adopter) - 75 mile range	EV1	X		
Electric Vehicle (Early Adopter) - 100 mile range	EV2	X		
Electric Vehicle (Early Adopter) - 150 mile range	EV3	X		
Electric Vehicle (Broad Market) - 150 mile range	EV4	X		
Fuel Cell Vehicle	FCV	X		
Mass Reduction - Level 1	MR1		X	
Mass Reduction - Level 2	MR2	X		
Mass Reduction - Level 3	MR3	X		
Mass Reduction - Level 4	MR4	X		
Mass Reduction - Level 5	MR5	X		
Low Rolling Resistance Tires - Level 1	ROLL1		X	
Low Rolling Resistance Tires - Level 2	ROLL2		X	
Low Rolling Resistance Tires - Level 3	ROLL3		X	
Low Drag Brakes	LDB		X	
Secondary Axle Disconnect	SAX		X	
Aero Drag Reduction, Level 1	AERO1		X	
Aero Drag Reduction, Level 2	AERO2	X		

Can the technology be applied to this vehicle? (division of vehicles into subclasses)

As part of its consideration of technological feasibility, the agency evaluates whether each technology could be implemented on all types and sizes of vehicles, and whether some differentiation is necessary in applying certain technologies to certain types and sizes of vehicles, and with respect to the cost incurred and fuel consumption and CO_2 emissions reduction achieved when doing so. The 2010 NAS Report differentiated technology application using eight vehicle “classes” (4 car classes and 4 truck classes).[129]NAS’s purpose in separating vehicles into these classes was to create groups of “like” vehicles, *i.e.*, vehicles similar in size, powertrain configuration, weight, and consumer use, and for which similar technologies are applicable. NAS also used these vehicle classes along with powertrain configurations (*e.g.*, 4 cylinder, 6 cylinder or 8 cylinder engines) to determine unique cost and effectiveness estimates for each class of vehicles.

NHTSA similarly differentiates vehicles by “subclass” for the purpose of applying technologies to “like” vehicles and assessing their incremental costs and effectiveness. These technology subclasses should not be confused with the regulatory classifications pursuant to 49 CFR Part 523. NHTSA assigns each vehicle manufactured in the rulemaking period to one of 12 subclasses: for passenger cars, Subcompact, Subcompact Performance, Compact, Compact Performance, Midsize, Midsize Performance, Large, and Large Performance; and for light trucks, Small SUV/Pickup/Van, Midsize SUV/Pickup/Van, Large SUV/Pickup/Van, and Minivan. The agency seeks comment on the appropriateness of these 12 subclasses for the MYs 2017-2025 timeframe.
For this NPRM, NHTSA divides the vehicle fleet into subclasses based on model inputs, and applies subclass-specific estimates, also from model inputs, of the applicability, cost, and effectiveness of each fuel-saving technology. The model’s estimates of the cost to improve the fuel economy of each vehicle model thus depend upon the subclass to which the vehicle model is assigned. Each vehicle’s subclass is stored in the market forecast file. When conducting a compliance analysis, if the Volpe model seeks to apply technology to a particular vehicle, it checks the market forecast to see if the technology is available and if the refresh/redesign criteria are met. If these conditions are satisfied, the model determines the vehicle’s subclass from the market data file, which it then uses to reference another input called the technology input file. NHTSA reviewed its methodology for dividing vehicles into subclasses for purposes of technology application that it used in the MY 2011 final rule and for the MYs 2012-2016 rulemaking, and concluded that the same methodology would be appropriate for this NPRM for MYs 2017–2025. The methodology is as follows:

NHTSA examined the car and truck segments separately. First, for the car segment, NHTSA plotted the footprint distribution of vehicles in the baseline vehicle fleet and divided that distribution into four equivalent footprint range segments. The footprint ranges were named Subcompact, Compact, Midsize, and Large classes in ascending order. Cars were then assigned to one of these classes based on their specific footprint

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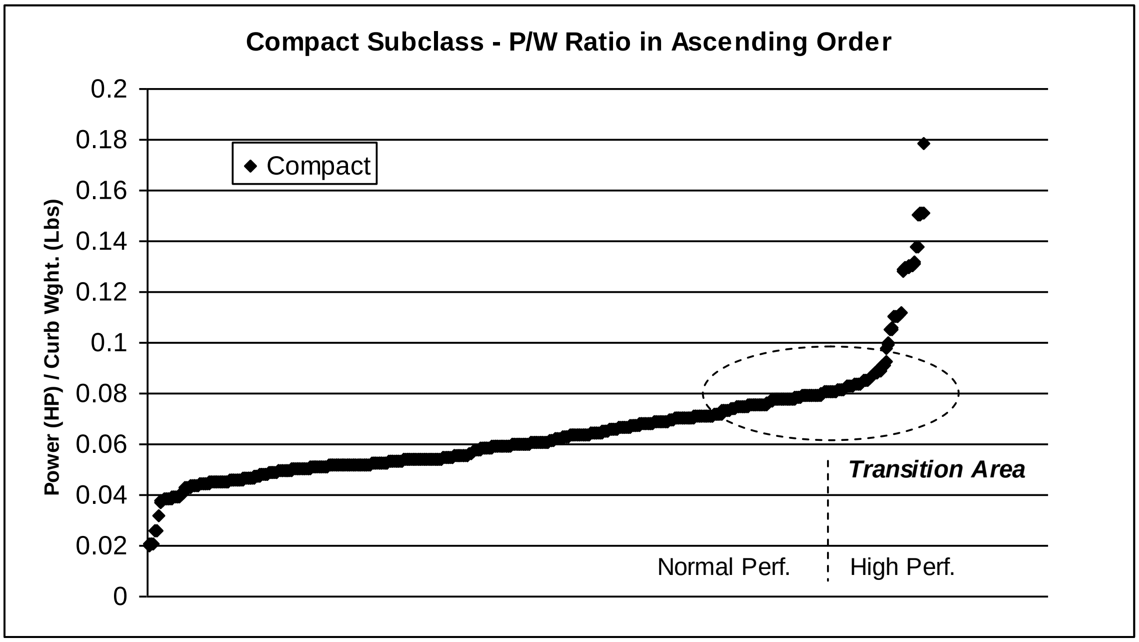
[129] The NAS classes included two-seater convertibles and coupes; small cars; intermediate and large cars; high-performance sedans; unit-body standard trucks; unit-body high-performance trucks; body-on-frame small and midsize trucks; and body

size. Vehicles in each range were then manually reviewed by NHTSA staff to evaluate and confirm that they represented a fairly reasonable homogeneity of size, weight, powertrains, consumer use, etc. However, each group contained some vehicles that were sports or high-performance models. Since different technologies and cost and effectiveness estimates may be appropriate for these type vehicles, NHTSA employed a performance subclass within each car subclass to maximize the accuracy of technology application. To determine which specific cars would be assigned to the performance subclasses, NHTSA graphed (in ascending rank order) the power-to-weight ratio for each vehicle in a subclass. An example of the Compact subclass plot is shown below in Figure V-16. The subpopulation was then manually reviewed by NHTSA staff to determine an appropriate transition point between “performance” and “non-performance” models within each class.

Figure V-15. Power/Weight Ratio for Compact Subclass



A total of eight classes (including performance subclasses) were identified for the car segment: Subcompact, Subcompact Performance, Compact, Compact Performance, Midsize, Midsize Performance, Large and Large Performance. In total, the number of cars that were ultimately assigned to a performance subclass was less than 10 percent. Table V-6 provides examples of the types of vehicles assigned to each car subclass.

Table V-8. Passenger Car Subclasses Example (MY 2008) Vehicles

Class	Example vehicles
Subcompact	Chevy Aveo, Hyundai Accent
Subcompact Performance	Mazda MX-5, BMW Z4
Compact	Chevy Cobalt, Nissan Sentra and Altima
Compact Performance	Audi S4, Mazda RX8
Midsize	Chevy Impala, , Toyota Camry, Honda Accord, Hyundai Azera
Midsize Performance	Chevy Corvette, Ford Mustang (V8), Nissan G37 Coupe
Large	Audi A8, Cadillac CTS and DTS
Large Performance	Bentley Arnage, Daimler CL600

For light trucks, as in the MYs 2012-2016 final rule, NHTSA found less of a distinction in the anticipated vehicle fleet during the model years covered by the rulemaking between SUVs and pickup trucks than appeared to exist in earlier rulemakings. We anticipate fewer ladder-frame and more unibody pickups, and that many pickups will share common powertrains with SUVs. Thus, SUVs and pickups are grouped in the same subclasses. Additionally, it made sense to carry forward NHTSA's decision from the MYs 2012-2016 final rule to employ a separate minivan class, because minivans (*e.g.*, the Honda Odyssey) are more car-like and differ significantly in terms of structural and other engineering characteristics as compared to other vans (*e.g.*, Ford's E-Series—also known as Econoline—vans) intended for more passengers and/or heavier cargo and which are more truck-like.

Thus, the remaining vehicles (other vans, pickups, and SUVs) were then segregated into three footprint ranges and assigned a class of Small Truck/SUV, Midsize Truck/SUV, and Large Truck/SUV based on their footprints. NHTSA staff then manually reviewed each population for inconsistent vehicles based on engine cylinder count, weight (curb and/or gross), or intended usage, since these are important considerations for technology application, and reassigned vehicles to classes as appropriate. This system produced four truck segment subclasses—minivans and small, medium, and large SUVs/Pickups/Vans. Table V-7 provides examples of the types of vehicles assigned to each truck subclass.

Table V-9. Light Truck Subclasses Example (MY 2008) Vehicles

Class	Example vehicles
Minivans	Dodge Caravan, Toyota Sienna
Small SUV/Pickup/Van	Ford Escape & Ranger, Nissan Rogue
Midsize SUV/Pickup/Van	Chevy Colorado, Jeep Wrangler, Toyota Tacoma
Large SUV/Pickup/Van	Chevy Silverado, Ford E-Series, Toyota Sequoia

As mentioned above, NHTSA employed this method for assigning vehicle subclasses for this proposal after reviewing the process used in the MYs 2012-2016 final rule and concluding that it continued to be a reasonable approach for purposes of this rulemaking. NHTSA believes that this method continues to substantially improve the overall accuracy of the results as compared to systems employed previously, due to the close manual review by NHTSA staff to ensure proper assignments, the use of performance subclasses in the car segment, and the condensing of subclasses in the truck segment, all of which further refine the system without overly complicating the CAFE modeling process. Nevertheless, NHTSA invites comments on the method of assigning vehicles to subclasses for the purposes of technology application in the CAFE model, and on the issue of technology-application subclasses generally. The agency is also seeking comment on the continued appropriateness of maintaining separate "performance" vehicle classes or if as fuel economy stringency increases the market for performance vehicles will decrease.

We note that EPA uses different classifications in its Lumped Parameter Model (LPM), OMEGA model, and cost analysis. Because the LPM uses only 6 vehicle classes, and because NHTSA relied on EPA's technology effectiveness estimates obtained through the LPM analysis for this rulemaking in the interest of harmonization, NHTSA needed to map its 12 vehicle subclasses into the LPM's 6 vehicle classes for purposes of developing subclass-specific technology effectiveness estimates. Table V-10 shows how NHTSA's vehicle classification lines up with EPA's classifications for purposes of developing the joint cost and effectiveness estimates.

Table V-10 Mapping between NHTSA and EPA Vehicle Classifications

NHTSA/CAFE model Classification	EPA Vehicle Class for Cost Purpose	EPA Lumped Parameter Model Classification	Example
Subcompact Subcompact Perf PC	Subcompact Car	Small Car	Yaris
Compact Compact Perf PC			
Mid-size PC Mid-size Perf PC	Small Car	Std Car	Camry
Large PC Large Perf PC	Large Car	Large Car	Chrysler 300
Small LT	Small Truck	Small MPV	Saturn Vue
Midsize LT	Minivan with Towing	Large MPV	Dodge Grand Caravan
MinVan LT			
Large LT	Large Truck	Truck	Ford F150

How much of the technology can be applied to the fleet this year? (phase-in caps)

Besides the refresh/redesign cycles used in the Volpe 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, the other constraint on technology application employed in NHTSA's analysis is "phase-in caps." Unlike vehicle-level cycle settings, phase-in caps constrain technology application at the vehicle manufacturer level.[130] 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 intended to be limited to, engineering resources at the OEM or supplier level, financial resources, restrictions on intellectual property that limit deployment, and/or limitations in material or component supply as a market for a new technology develops. The inclusion of phase-in caps helps to ensure that resource capacity and other limitations are accounted for in the modeling process. At a high level, phase-in caps, refresh/redesign cycles and the logic of the model itself work in conjunction with one another to avoid the modeling process out-pacing an OEM's limited pool of available resources during the rulemaking time frame and the years leading up to the rulemaking time frame, especially in years where many models may be scheduled for refresh or

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[130] While phase-in caps are expressed as specific percentages of a manufacturer's fleet to which a technology may be applied in a given model year, phase-in caps cannot always be applied as precise limits, and the Volpe model in fact allows "override" of a cap in certain circumstances. When only a small portion of a phase-in cap limit remains, or when the cap is set to a very low value, or when a manufacturer has a very limited product line, the cap might prevent the technology from being applied at all since any application would cause the cap to be exceeded. Therefore, the Volpe model evaluates and enforces each phase-in cap constraint after it has been exceeded by the application of the technology (as opposed to evaluating it before application), which can result in the described overriding of the cap.

redesign. We emphasize that phase-in caps are not used to prescribe technology application rates; to NHTSA, phase-in caps represent the maximum amount of technology that the industry could apply in a given year recognizing the limitations described above. Phase-in caps, in combination with other constraints, thus help to ensure technological feasibility and economic practicability in determining the stringency of the standards. Despite the available lead time, these constraints remain important for this round of rulemaking: even though this rulemaking is being proposed 5 years before it takes effect, OEM's will still be utilizing their limited resources to meet the MYs 2012-2016 CAFE standards.

NHTSA has been developing the concept of phase-in caps for purposes of the agency's modeling analysis over the course of the last several CAFE rulemakings, as discussed in greater detail in the MY 2011 final rule,[131] in the MY 2012-2016 final rule and Chapter 3 of the Joint TSD. The MYs 2012-2016 final rule, like the MY 2011 final rule, employed non-linear phase-in caps (that is, caps that varied from year to year) that were designed to respond to previously received comments on technology deployment.

For purposes of this NPRM, as in the MY 2011 and MYs 2012-2016 final rules, NHTSA combines phase-in caps for some groups of similar technologies, such as valve phasing technologies that are applicable to different forms of engine design (SOHC, DOHC, OHV), since they are very similar from an engineering and implementation standpoint. When the phase-in caps for two technologies are combined, the maximum total application of either or both to any manufacturer's fleet is limited to the value of the cap.[132]

In developing phase-in cap values for purposes of this NPRM, NHTSA reviewed the MYs 2012-2016 final rule's phase-in caps, which for the majority of technologies were set to reach 85 or 100 percent by MY 2016, although more advanced technologies like diesels and strong hybrids reached only 15 percent by MY 2016. The phase-in caps used in the MYs 2012-2016 final rule were developed to harmonize with the similar caps used in EPA's modeling, and reflected the fact that manufacturers, as part of the agreements supporting the National Program, appeared to be anticipating higher technology application rates than assumed by NHTSA in prior rulemaking analyses. NHTSA determined that these phase-in caps for MY 2016 were still reasonable and thus used those caps as the starting point for the MYs 2017-2025 phase-in caps. For many of the carryover technologies, this means that for MYs 2017-2025 the phase-in caps are assumed to be 100 percent. For the phase-in caps for the newly defined technologies that will be entering the market just before or during the MYs 2017-2025 time frame, as discussed in more detail in Chapter 3 of the Joint TSD, NHTSA, along with EPA, used confidential OEM submissions, trade press articles, company publications and press releases to estimate their values using engineering judgment,. For example, advanced cooled EGR engines are assigned a phase-in cap of 3 percent per year through MY 2021, and then 10 percent per year through 2025. The agency seeks comment on the

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[132] *See* 74 FR at 14270 (Mar. 30, 2009) for further discussion and examples.

appropriateness of both the carryover phase-in caps and the newly defined ones proposed in this NPRM.

Table V-10shows phase-in rates, on a year-by-year basis, for the technologies used in the CAFE model for this NPRM analysis. Most technologies are available at a rate of either 85 percent or 100 percent beginning in 2016. Some advanced technologies expected to enter the market in the near future, such as EGR Boost, follow a 3 percent annual cap increase from 2016 to 2021, and then approximately 10 percent from 2021 to 2025. Diesels follow an annual 3 percent increase in phase-in cap through 2025. Hybrids follow a 3 percent annual increase from 2016 to 2012, then 5 percent from 2021 to 2015. PHEVs and EVs follow a 1 percent annual cap increase.

Lower phase-in caps for Alternative 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 V-11. Phase-in Caps for Technologies Used in 2017+ NPRM Analysis for 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) - 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) - SD	TRBDS1_SD	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) - MD	TRBDS1_MD	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) - LD	TRBDS1_LD	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) - SD	TRBDS2_SD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - MD	TRBDS2_MD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - LD	TRBDS2_LD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
CEGR- Level 1 (24 bar BMEP) – SD	CEGR1_SD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
CEGR - Level 1 (24 bar BMEP) – MD	CEGR1_MD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
CEGR - Level 1 (24 bar BMEP) – LD	CEGR1_LD	0%	0%	0%	3%	6%	9%	12%	15%	18%	21%	24%	27%	30%	45%	60%	75%	75%
CEGR - Level 2 (27 bar BMEP) – SD	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	3%	6%	9%	12%	15%	25%	35%	45%	50%
CEGR - Level 2 (27 bar BMEP) – MD	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	3%	6%	9%	12%	15%	25%	35%	45%	50%
CEGR - Level 2 (27 bar BMEP) – LD	CEGR2_LD	0%	0%	0%	0%	0%	0%	0%	0%	3%	6%	9%	12%	15%	25%	35%	45%	50%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	3%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	0%	3%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
Advanced Diesel - Large Displacement	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%

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
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 (Early Adopter) - 100 mile range	EV2	0%	0%	0%	1%	2%	3%	4%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	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 Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
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	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	100%	100%	100%	100%	100%	100%	100%

Once the technology is applied, how much does it improve fuel economy? (effectiveness estimates)

In the MYs 2012-2016 final rule, NHTSA and EPA based technology effectiveness estimates on two primary sources: NHTSA's 2011 final rule, which was supported by recommendations from Ricardo, Inc. under contract to NHTSA; and EPA's 2008 Staff Technical Report,[133],which was supported by vehicle simulation modeling performed by Ricardo in 2007.
EPA built upon its 2007 vehicle simulation work by again hiring Ricardo to perform additional vehicle simulation modeling that could be used to derive the effectiveness estimates for this proposal. Ricardo used its proprietary dynamic vehicle simulation model, which they developed and implemented in MSC.EASY5^{TM}, for this simulation work. MSC.EASY5^{TM} is a commercially available software package used in industry for vehicle system analysis. In the current study, Ricardo has expanded the technology list previously modeled and included the following new engine and vehicle technologies:

- Advanced, highly downsized, high BMEP turbocharged engine
- High efficiency 8-speed automatic and DCT transmission
- Optimized shift schedule to achieve best Brake Specific Fuel Consumption (BSFC)
- Atkinson-cycle engines for hybrid vehicles

The new analysis also includes modeling of the following hybrid architectures used in the NPRM analysis:

- Stop-start technology
- P2 hybrid

Detailed information about Ricardo's work for this project can be found at Docket No, NHTSA-2010-0131, and also in Section 3.3.1 of Chapter 3 of the draft joint TSD.
Because the Ricardo findings are for predefined packages/combinations of technologies, the agencies needed a way to extract the individual effectiveness for each technology in order to be able to apply them one at a time or create different packages/combinations of technologies. To that end, EPA used the new Ricardo results to calibrate and update EPA's Lumped Parameter Model (LPM), available at Docket No. NHTSA 2010-0131.The lumped parameter tool is a spreadsheet model used to develop the technology effectiveness estimates for this NPRM analysis, that represents energy consumption in terms of average performance over the fuel economy test procedure, rather than explicitly analyzing specific drive cycles. The tool begins with an apportionment of fuel consumption across several loss mechanisms and accounts for the average extent to which different technologies affect these loss mechanisms using estimates of engine, drivetrain and vehicle characteristics that are averaged over the EPA fuel economy drive cycle.

As part of the calibration/updating process, EPA adjusted the LPM inputs to ensure that the results closely aligned with those of the Ricardo work. Thus the results of this analysis using the

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[133] 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 NHTSA-2010-0131)

LPM were generally consistent with Ricardo's most recent full-scale vehicle simulation modeling.[134] Detailed information about how the LPM works and how EPA used it to develop technology effectiveness values for this analysis can be found in Chapter 3 of the draft joint TSD.

The technology effectiveness inputs used in the CAFE model for this analysis are based on entirely on the outputs of the newly updated LPM, and thus incorporate the Ricardo simulation work from 2007 and 2011. Table V-12 to Table V-22 below define how NHTSA mapped technology effectiveness calculations from the LPM into CAFE model-specific inputs. The LPM defines technologies specific to EPA's OMEGA model so NHTSA had to create a process of mapping technologies in the LPM that are consistent with those found in the CAFE model's decision trees. For example, to generate the effectiveness for the Improved Automatic Transmission Controls/Externals (IATC) NHTSA had to enable both "Early Upshift" and "Aggressive Torque Converter Lockup" in the LPM. NHTSA used this mapping technique to calculate the absolute effectiveness of each technology relative to a baseline vehicle. NHTSA then used these absolute effectiveness estimates, for each step in the decision trees, to calculate the incremental effectiveness estimates for each technology, which is what the CAFE model ultimately needs to analyze a heterogeneous fleet baseline fleet on a model year by model year basis.

Table V-12. CAFE Model and LPM Mapping for Engine Technologies (non-Valvetrain Dependent Engine Technologies)

NHTSA Techs	**LPM Selection**	
Model Years	**2012-2016**	**2017+**
LUB1	Low Fric Lubes	Low Fric Lubes
EFR1	Low Fric Lubes EF Reduction (Level=1)	Low Fric Lubes EF Reduction (Level=1)
LUB2_EFR2		EF Reduction (Level=2)

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[134] Regardless of a generally consistent set of results for the vehicle class and set of technologies studied, the lumped parameter tool is not a full vehicle simulation and cannot replicate the physics of such a simulation.

Table V-13. CAFE Model and LPM Mapping for Engine Technologies
(SOHC Path)

NHTSA Techs	**LPM Selection**	
Model Years	**2012-2016**	**2017+**
SOHC Path		
CCPS	Low Fric Lubes EF Reduction (Level=1) CCP	EF Reduction (Level=2) CCP
DVVLS	Low Fric Lubes EF Reduction (Level=1) CCP DVVL	EF Reduction (Level=2) CCP DVVL
DEACS	Low Fric Lubes EF Reduction (Level=1) CCP DEAC	EF Reduction (Level=2) CCP DEAC
SGDI	Low Fric Lubes EF Reduction (Level=1) CCP DEAC GDI (stoich)	EF Reduction (Level=2) CCP DEAC GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel	-	Advanced Diesel (2020)

Table V-14. CAFE Model and LPM Mapping for Engine Technologies

(DOHC DVVL Path)

NHTSA Techs	**LPM Selection**	
Model Years	**2012-2016**	**2017+**
DOHC DVVL Path		
ICP	Low Fric Lubes EF Reduction (Level=1) ICP	EF Reduction (Level=2) ICP
DCP	Low Fric Lubes EF Reduction (Level=1) DCP	EF Reduction (Level=2) DCP
DVVLD	Low Fric Lubes EF Reduction (Level=1) DCP DVVL	EF Reduction (Level=2) DCP DVVL
DEACD	Low Fric Lubes EF Reduction (Level=1) DCP DEAC	EF Reduction (Level=2) DCP DEAC
SGDI	Low Fric Lubes EF Reduction (Level=1) DCP DEAC GDI (stoich)	EF Reduction (Level=2) DCP DEAC GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel	-	Advanced Diesel (2020)

Table V-15. CAFE Model and LPM Mapping for Engine Technologies
(DOHC CVVL Path)

NHTSA Techs	LPM Selection	
Model Years	**2012-2016**	**2017+**
DOHC CVVL Path		
CVVL	Low Fric Lubes EF Reduction (Level=1) DCP CVVL	EF Reduction (Level=2) DCP CVVL
DEACD	This is ignored because effectiveness is less than CVVL	
SGDI	Low Fric Lubes EF Reduction (Level=1) DCP CVVL GDI (stoich)	EF Reduction (Level=2) DCP CVVL GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel	-	Advanced Diesel (2020)

Table V-16. CAFE Model and LPM Mapping for Engine Technologies
(OHV Path)

NHTSA Techs	**LPM Selection**	
Model Years	**2012-2016**	**2017+**
OHV Path		
DEACO	Low Fric Lubes EF Reduction (Level=1) DEAC	EF Reduction (Level=2) DEAC
VVA	Low Fric Lubes EF Reduction (Level=1) CCP DEACO	EF Reduction (Level=2) CCP DEACO
SGDI	Low Fric Lubes EF Reduction (Level=1) CCP DEACO GDI (stoich)	EF Reduction (Level=2) CCP DEACO GDI (stoich)
TRBDS1 18bar	Low Fric Lubes EF Reduction (Level=1) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)	EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=33%)
TRBDS2 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) Turbo/Downsize (gas engines only) (Percent=50%)
CEGR1 24bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=50%)
CEGR2 27bar		EF Reduction (Level=2) DCP DVVL GDI (stoich) w/ cooled EGR Turbo/Downsize (gas engines only) (Percent=56%)
Adv Diesel	-	Advanced Diesel (2020)

Table V-17. CAFE Model and LPM Mapping for Transmission Technologies

NHTSA Techs	**LPM Selection**	
Model Years	**2012-2016**	**2017+**
IATC	Early upshift (formerly ASL) Agg TC Lockup	Early upshift (formerly ASL) Agg TC Lockup
Baseline for the following technologies is 5-speed automatic transmission		
NAUTO	6-spd gearbox Early upshift (formerly ASL) Agg TC Lockup High efficiency gear box (auto) (Percent= 7%)	6-spd gearbox Early upshift (formerly ASL) Agg TC Lockup High efficiency gear box (auto) (Percent= 7%)
DCT (Dry)	6-spd gearbox DCT Dry Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)	6-spd gearbox DCT Dry Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
DCT (Wet)	6-spd gearbox DCT Wet Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)	6-spd gearbox DCT Wet Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
8 SPD (Auto)		8-spd gearbox Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
8 SPD (Dry DCT)		8-spd gearbox DCT Dry Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
8 SPD (Wet DCT)		8-spd gearbox DCT Wet Early upshift (formerly ASL) High efficiency gear box (auto) (Percent= 7%)
HETRANS		*(Additional Selection over previous selection)* High efficiency gear box (auto) (Percent= 25%)
SHIFTOPT		*(Additional Selection over previous selection)* Optmized shift strategy*

Notes
* Make sure "Early upshift (formerly ASL)" is turned off.

Table V-18. CAFE Model and LPM Mapping for Accessory Technologies

NHTSA Techs	LPM Selection
EPS	EPS
IACC1	EPS Electric access (12v) High eff alternator (70%)
IACC2	EPS Electric access (12v) High eff alternator (70%) Alternator regen on braking
MHEV (12v SS)	EPS Electric access (12v) High eff alternator (70%) Alternator regen on braking 12V SS (idle off only)

Table V-19. CAFE Model and LPM Mapping for Strong Hybrid Technologies

(MY2012-2016 Technologies)

SHEV1 (non-towing) (subcompact PC, compact PC with dry DCT)		SHEV1 (non-towing) (midsize PC, large PC, small LT with wet DCT)		SHEV1 (towing)* (Midsize LT, Minivan and Large LT with ATX)	
	% or Level		*% or Level*		*% or Level*
Low Fric Lubes		Low Fric Lubes		Low Fric Lubes	
EF Reduction	1	EF Reduction	1	EF Reduction	1
DCP		DCP		DCP	
DVVL		DVVL		DVVL	
				Turbo/Downsize (gas engines only)	35%
6-spd gearbox		6-spd gearbox		6-spd gearbox	
DCT Dry		DCT Wet			
Early upshift (formerly ASL)		Early upshift (formerly ASL)		Early upshift (formerly ASL)	
				Agg TC Lockup	
High efficiency gearbox (auto)	7%	High efficiency gearbox (auto)	7%	High efficiency gearbox (auto)	7%
EPS		EPS		EPS	
Electric access (12V)		Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)		GDI (stoich)	
	Motor kW		*Motor kW*		*Motor kW*
Hybrid drivetrain	17	Hybrid drivetrain	24	Hybrid drivetrain	36
Atkinson cycle engine		Atkinson cycle engine			

Notes

*Vehicle with towing will have automatic transmission and non-Atkinson cycle engine with downsizing.

Table V-20. CAFE Model and LPM Mapping for Strong Hybrid Technologies

(MY2017+ Technologies)

SHEV2 (non-towing) (subcompact PC, compact PC with dry DCT)		SHEV2 (non-towing) (midsize PC, large PC, small LT with wet DCT)		SHEV2 (towing)* (Midsize LT, Minivan and Large LT with ATX)	
	% or Level		*% or Level*		*% or Level*
EF Reduction	2	EF Reduction	2	EF Reduction	2
DCP		DCP		DCP	
DVVL		DVVL		DVVL	
				Turbo/Downsize (gas engines only)	48%
8-spd gearbox		8-spd gearbox		8-spd gearbox	
DCT Dry		DCT Wet			
Optimized shift strategy		Optimized shift strategy		Optimized shift strategy	
				Agg TC Lockup	
High efficiency gearbox (auto)	25%	High efficiency gearbox (auto)	25%	High efficiency gearbox (auto)	25%
Alternator regen on braking		Alternator regen on braking		Alternator regen on braking	
EPS		EPS		EPS	
Electric access (12V)		Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)		GDI (stoich)	
	Motor kW		*Motor kW*		*Motor kW*
Hybrid drivetrain	17	Hybrid drivetrain	24	Hybrid drivetrain	36
Atkinson cycle engine		Atkinson cycle engine			

Notes

*Vehicle with towing will have automatic transmission and non-Atkinson cycle engine with downsizing.

Table V-21. CAFE Model and LPM Mapping for Plug-in Hybrid Technologies (20-Mile Range)

PHEV 20 Mile (subcompact PC, compact PC with dry DCT)		PHEV 20 Mile (midsize PC, large PC, small LT with wet DCT)	
	% or Level		*% or Level*
EF Reduction	2	EF Reduction	2
DCP		DCP	
DVVL		DVVL	
8-spd gearbox		8-spd gearbox	
DCT Dry		DCT Wet	
Optimized shift strategy		Optimized shift strategy	
High efficiency gearbox (auto)	25%	High efficiency gearbox (auto)	25%
Alternator regen on braking		Alternator regen on braking	
EPS	100%	EPS	100%
Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)	
	Motor kW		*Motor kW*
Hybrid drivetrain	30	Hybrid drivetrain	30
Atkinson cycle engine		Atkinson cycle engine	
Plug-In	40%	Plug-In	40%

Table V-22. CAFE Model and LPM Mapping for Plug-in Hybrid Technologies (40-Mile Range)

PHEV 40 Mile (subcompact PC, compact PC with dry DCT)		PHEV 40 Mile (midsize PC, large PC, small LT with wet DCT)	
	% or Level		*% or Level*
EF Reduction	2	EF Reduction	2
DCP		DCP	
DVVL		DVVL	
8-spd gearbox		8-spd gearbox	
DCT Dry		DCT Wet	
Optimized shift strategy		Optimized shift strategy	
High efficiency gearbox (auto)	25%	High efficiency gearbox (auto)	25%
Alternator regen on braking		Alternator regen on braking	
EPS	100%	EPS	100%
Electric access (12V)		Electric access (12V)	
High efficiency alternator (70%)		High efficiency alternator (70%)	
GDI (stoich)		GDI (stoich)	
	Motor kW		*Motor kW*
Hybrid drivetrain	30	Hybrid drivetrain	30
Atkinson cycle engine		Atkinson cycle engine	
Plug-In	63%	Plug-In	63%

We note that the U.S. D.O.T. Volpe Center, which supports NHTSA in its CAFE rulemaking work, has contracted with Argonne National Laboratory (ANL) to provide full vehicle simulation modeling support for this MYs 2017-2025 rulemaking. While modeling was not completed in time for use in this NPRM, NHTSA expects to use this modeling to validate and possibly update technology effectiveness estimates and synergy factors as appropriate for the CAFE model for the final rulemaking analysis. This simulation modeling will be 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 ANL's expertise with advanced vehicle technologies.

Synergies

When two or more technologies are added to a particular vehicle model to improve its fuel efficiency, the resultant fuel consumption reduction may sometimes be higher or lower than the product of the individual effectiveness values for those items.[135] This may occur because one or more technologies applied to the same vehicle partially address the same source (or sources) of engine, drivetrain or vehicle losses. Alternately, this effect may be seen when one technology shifts the engine operating points, and therefore increases or reduces the fuel consumption reduction achieved by another technology or set of technologies. The difference between the observed fuel consumption reduction associated with a set of technologies and the product of the

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[135] More specifically, the resultant is calculated as the products of the differences between the numeric value one (i.e., 1.0) and the technology-specific levels of effectiveness in reducing fuel consumption (expressed as a numeric value also, i.e., 10% = 0.10). For example, not accounting for interactions, if technologies A and B are estimated to reduce fuel consumption by 10% (i.e., 0.1) and 20% (i.e., 0.2) respectively, the "product of the individual effectiveness values" would be (1 – 0.1) times (1 – 0.2), or 0.9 times 0.8, which equals 0.72, corresponding to a combined effectiveness of (1 - .72 = .28) or 28% rather than the 30% obtained by adding 10% to 20%. The "synergy factors" discussed in this section further adjust these multiplicatively combined effectiveness values.

individual effectiveness values in that set is referred to as a "synergy." Synergies may be positive (and thus result in greater fuel consumption reduction compared to the product of the individual effects) or negative (and thus result in less fuel consumption reduction). An example of a positive synergy might be a vehicle technology that reduces road loads at highway speeds (*e.g.*, lower aerodynamic drag or low rolling resistance tires), that could effectively extend the vehicle operating range over which cylinder deactivation may be employed, thus allowing a greater fuel consumption reduction than anticipated or predicted by analysis. An example of a negative synergy might be a variable valvetrain technology, which reduces pumping losses by altering the profile of the engine speed/load map, and a six-speed automatic transmission, which shifts the engine operating points to a portion of the engine speed/load map where pumping losses are less significant, leaving less opportunity for the combined technologies to decrease fuel consumption. As the complexity of the technology combinations is increased, and the number of interacting technologies grows accordingly, it becomes increasingly important to account for these synergies.

Because NHTSA applies technologies individually in its modeling analysis, NHTSA incorporates synergistic effects between pairings of individual technologies. The use of discrete technology pair incremental synergies is similar to that in DOE's National Energy Modeling System (NEMS).[136] Inputs to the CAFE model incorporate NEMS-identified pairs, as well as additional pairs from the specific set of technologies considered in the CAFE model. For the MYs 2012-2016 final rule and the MY 2011 final rule NHTSA used a modified version of the lumped parameter tool to evaluate accurate synergy values. During the 2011 final rule analysis, with the assistance of Ricardo, NHTSA modified the lumped parameter tool by updating the list of technologies and their associated effectiveness values, and expanding the list of synergy pairings based on further consideration of the technologies for which a competition for losses would be expected, for the purposes of evaluating appropriate synergy values. For this proposal, NHTSA used the version of the lumped parameter model as recently updated by EPA, as discussed above, to evaluate appropriate synergy values.

As was done for the individual technology effectiveness estimates, NHTSA used the 6 unique vehicle classes in the lumped parameter tool to evaluate the synergies for each if the 12 vehicle subclasses. NHTSA systematically and thoroughly "walked" through the CAFE model's application of individual technologies, via the decision trees, to evaluate the synergies between pairs of technologies. Once the synergies for a vast majority of the technology pairs were generated, NHTSA iteratively evaluated hundreds of technology combinations, and all the steps that build up to the different combinations, to ensure that these combinations of technologies with their individual effectiveness estimates and corresponding synergy values resulted in overall fuel consumptions reductions that closely aligned with the overall fuel consumption reductions that were predicted by the lumped parameter tool. Basically, the lumped parameter tool was used to calibrate the synergy values to make sure the overall fuel consumptions reductions for the various combinations of technologies closely align with those predicted by the lumped parameter tool. The agency paid special attention to technology combinations that the model most often tends to form dynamically. This iterative process was conducted for each of the 6

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[136] U.S. Department of Energy, Energy Information Administration, *Transportation Sector Module of the National Energy Modeling System: Model Documentation 2009*, June 2009, Washington, DC, DOE/EIAM070(2009), at 26-27. *Available at* ftp://ftp.eia.doe.gov/modeldoc/m070(2009).pdf (last accessed Nov. 7, 2011).

vehicle classes, utilized by the lumped parameter tool, to develop vehicle class specific synergy factors. While the evaluation of technology combinations was not exhaustive, NHTSA believes that the hundreds of combinations evaluated were more than adequate to ensure accurate results, which replicate the results from the lumped parameter tool.

NHTSA notes that synergies that occur within a particular decision tree are already accounted for within the incremental effectiveness values assigned for each technology, and therefore additional synergy pairs for these technologies are not required. For example, all engine technologies take into account the synergies that occur with the preceding/existing engine technologies, and all transmission technologies take into account synergies of preceding transmission technologies, etc. These synergy factors are accounted for in the fuel consumption improvement estimates in the input files used by the CAFE model.

For applying incremental synergy factors in separate path technologies, *i.e.*, between two or more decision trees, the CAFE model uses an input table (see Table V-21 a-d) that lists technology pairings and incremental synergy factors associated with those pairings (most of which are between engine technologies and transmission/ electrification/hybrid technologies). When a technology is applied to a vehicle by the CAFE model, all instances of that technology in the incremental synergy table which match technologies already applied to the vehicle (either pre-existing or previously applied by the CAFE model) are summed and applied to the fuel consumption improvement factor of the technology being applied. Synergies between the strong and plug-in hybrid technologies and transmission and electrification technologies are included in the incremental value for the specific hybrid or plug-in hybrid technology because the model applies technologies in the order of the most effectiveness for least cost and also applies all available electrification and transmission technologies before applying strong and plug-in hybrid technologies.

Table V-23a Synergy pairings and values

		Fuel Consumption Improvement Synergy values by Vehicle Class Positive values are [positive] synergies, negative values are dissynergies. Blank cells are assumed to be zero.					
Technology A	**Technology B**	**Subcompact PC**	**Subcompact Perf. PC**	**Compact PC**	**Compact Perf. PC**	**Midsize PC**	**Midsize Perf. PC**
DCP	SHFTOPT	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%
DCP	IACC1	-0.20%	-0.20%	-0.20%	-0.20%	-0.40%	-0.40%
DCP	IACC2	-0.40%	-0.40%	-0.40%	-0.40%	-0.80%	-0.80%
CCPS	SHFTOPT	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%
CCPS	IACC1	-0.20%	-0.20%	-0.20%	-0.20%	-0.40%	-0.40%
CCPS	IACC2	-0.40%	-0.40%	-0.40%	-0.40%	-0.80%	-0.80%
DVVLS	IATC	-0.40%	-0.40%	-0.40%	-0.40%	-0.60%	-0.60%
DVVLS	MHEV	-0.50%	-0.50%	-0.50%	-0.50%	-0.30%	-0.30%
DVVLS	IACC2	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%
DVVLS	8SPD	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%
DEACS	IATC	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DVVLD	IATC	-0.40%	-0.40%	-0.40%	-0.40%	-0.60%	-0.60%
DVVLD	MHEV	-0.50%	-0.50%	-0.50%	-0.50%	-0.30%	-0.30%
DVVLD	IACC2	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%
DVVLD	8SPD	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%
CVVL	IATC	-0.40%	-0.40%	-0.40%	-0.40%	-0.60%	-0.60%
CVVL	MHEV	-0.50%	-0.50%	-0.50%	-0.50%	-0.30%	-0.30%
CVVL	IACC2	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%
CVVL	8SPD	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%
DEACD	IATC	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%
DEACO	IATC	0.00%	0.00%	0.00%	0.00%	-0.60%	-0.60%
DEACO	MHEV	-0.50%	-0.50%	-0.50%	-0.50%	-0.30%	-0.30%
DEACO	IACC1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DEACO	IACC2	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%
DEACO	8SPD	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%	-0.70%
VVA	IATC	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%
VVA	SHFTOPT	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%	-0.60%
VVA	IACC1	-0.20%	-0.20%	-0.20%	-0.20%	-0.40%	-0.40%
VVA	IACC2	-0.40%	-0.40%	-0.40%	-0.40%	-0.80%	-0.80%
TRBDS1_SD	IATC	-0.50%	-0.50%	-0.50%	-0.50%	-0.80%	-0.80%
TRBDS1_MD	IATC	-0.50%	-0.50%	-0.50%	-0.50%	-0.80%	-0.80%
TRBDS1_LD	IATC	-0.50%	-0.50%	-0.50%	-0.50%	-0.80%	-0.80%
TRBDS1_SD	SHFTOPT	-0.20%	-0.20%	-0.20%	-0.20%	-0.70%	-0.70%
TRBDS1_MD	SHFTOPT	-0.20%	-0.20%	-0.20%	-0.20%	-0.70%	-0.70%
TRBDS1_LD	SHFTOPT	-0.20%	-0.20%	-0.20%	-0.20%	-0.70%	-0.70%
TRBDS1_SD	8SPD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_MD	8SPD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_LD	8SPD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_SD	MHEV	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_MD	MHEV	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_LD	MHEV	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_SD	IACC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_MD	IACC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS1_LD	IACC2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
TRBDS2_SD	NAUTO	-0.50%	-0.50%	-0.50%	-0.50%	-1.20%	-1.20%
TRBDS2_MD	NAUTO	-0.50%	-0.50%	-0.50%	-0.50%	-1.20%	-1.20%

Table V-21b Synergy pairings and values

Technology A	Technology B	Subcompact PC	Subcompact Perf. PC	Compact PC	Compact Perf. PC	Midsize PC	Midsize Perf. PC
TRBDS2_LD	NAUTO	-0.50%	-0.50%	-0.50%	-0.50%	-1.20%	-1.20%
TRBDS2_SD	EPS	-0.20%	-0.20%	-0.20%	-0.20%	0.00%	0.00%
TRBDS2_MD	EPS	-0.20%	-0.20%	-0.20%	-0.20%	0.00%	0.00%
TRBDS2_LD	EPS	-0.20%	-0.20%	-0.20%	-0.20%	0.00%	0.00%
TRBDS2_SD	IACC2	-0.10%	-0.10%	-0.10%	-0.10%	0.00%	0.00%
TRBDS2_MD	IACC2	-0.10%	-0.10%	-0.10%	-0.10%	0.00%	0.00%
TRBDS2_LD	IACC2	-0.10%	-0.10%	-0.10%	-0.10%	0.00%	0.00%
CEGR1_SD	IACC2	-0.20%	-0.20%	-0.20%	-0.20%	0.00%	0.00%
CEGR1_MD	IACC2	-0.20%	-0.20%	-0.20%	-0.20%	0.00%	0.00%
CEGR1_LD	IACC2	-0.20%	-0.20%	-0.20%	-0.20%	0.00%	0.00%
CEGR2_SD	NAUTO	-0.60%	-0.60%	-0.60%	-0.60%	-0.80%	-0.80%
CEGR2_MD	NAUTO	-0.60%	-0.60%	-0.60%	-0.60%	-0.80%	-0.80%
CEGR2_LD	NAUTO	-0.60%	-0.60%	-0.60%	-0.60%	-0.80%	-0.80%
DCT	MHEV	-0.30%	-0.30%	-0.30%	-0.30%	-0.30%	-0.30%
SHFTOPT	MHEV	-0.30%	-0.30%	-0.30%	-0.30%	-0.30%	-0.30%
ROLL1	AERO1	0.20%	0.20%	0.20%	0.20%	0.20%	0.20%
ROLL2	AERO2	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
MR1	VVA	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MR1	DCP	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MR1	CCPS	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MR2	ROLL1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MR4	TRBDS1_SD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MR4	TRBDS1_MD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MR4	TRBDS1_LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MR4	AERO2	0.40%	0.40%	0.40%	0.40%	0.40%	0.40%
MR5	ROLL1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
ADSL_SD	IATC	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
ADSL_MD	IATC	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
ADSL_LD	IATC	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
NAUTO	SAX	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%
SHEV1	AERO2	1.0%	1.0%	1.0%	1.0%	1.4%	1.4%
SHEV1	ROLL1	0.7%	0.7%	0.7%	0.7%	0.8%	0.8%
SHEV1	MR2	-0.5%	-0.5%	-0.5%	-0.5%	-0.4%	-0.4%
SHEV1	MR3	-0.2%	-0.2%	-0.2%	-0.2%	-0.1%	-0.1%
SHEV1	MR4	-0.3%	-0.3%	-0.3%	-0.3%	-0.2%	-0.2%
SHEV1	MR5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SHEV1_2	AERO2	0.2%	0.2%	0.2%	0.2%	-0.1%	-0.1%
SHEV1_2	ROLL2	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
SHEV1_2	MR2	0.1%	0.1%	0.1%	0.1%	-0.1%	-0.1%
SHEV1_2	MR3	0.0%	0.0%	0.0%	0.0%	-0.2%	-0.2%
SHEV1_2	MR4	0.0%	0.0%	0.0%	0.0%	-0.2%	-0.2%
SHEV1_2	MR5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SHEV2	AERO2	1.2%	1.2%	1.2%	1.2%	1.3%	1.3%
SHEV2	ROLL2	1.0%	1.0%	1.0%	1.0%	1.1%	1.1%
SHEV2	MR2	-0.4%	-0.4%	-0.4%	-0.4%	-0.5%	-0.5%
SHEV2	MR3	-0.2%	-0.2%	-0.2%	-0.2%	-0.3%	-0.3%
SHEV2	MR4	-0.3%	-0.3%	-0.3%	-0.3%	-0.4%	-0.4%
SHEV2	MR5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV1	AERO2	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%
PHEV1	ROLL2	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%

Table V-21c Synergy pairings and values

		Fuel Consumption Improvement Synergy values by Vehicle Class Positive values are [positive] synergies, negative values are dissynergies. Blank cells are assumed to be zero.					
Technology A	**Technology B**	**Large PC**	**Large Perf. PC**	**Minivan LT**	**Small LT**	**Midsize LT**	**Large LT**
DCP	SHFTOPT	-0.80%	-0.80%	-0.8%	-0.6%	-0.8%	-0.7%
DCP	IACC1	-0.40%	-0.40%	-0.1%	-0.3%	-0.1%	-0.4%
DCP	IACC2	-0.80%	-0.80%	-0.6%	-0.5%	-0.6%	-0.6%
CCPS	SHFTOPT	-0.80%	-0.80%	-0.8%	-0.6%	-0.8%	-0.7%
CCPS	IACC1	-0.40%	-0.40%	-0.1%	-0.3%	-0.1%	-0.4%
CCPS	IACC2	-0.80%	-0.80%	-0.6%	-0.5%	-0.6%	-0.6%
DVVLS	IATC	-0.80%	-0.80%	-0.7%	-0.5%	-0.7%	-0.5%
DVVLS	MHEV	-0.40%	-0.40%	-0.4%	-0.2%	-0.4%	-0.7%
DVVLS	IACC2	-0.90%	-0.90%	-0.7%	-0.6%	-0.7%	-0.8%
DVVLS	8SPD	-0.80%	-0.80%	-0.8%	-0.6%	-0.8%	-0.6%
DEACS	IATC	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%
DVVLD	IATC	-0.70%	-0.70%	-0.5%	-0.5%	-0.5%	-0.6%
DVVLD	MHEV	-0.40%	-0.40%	-0.4%	-0.2%	-0.4%	-0.7%
DVVLD	IACC2	-0.90%	-0.90%	-0.7%	-0.6%	-0.7%	-0.8%
DVVLD	8SPD	-0.80%	-0.80%	-0.8%	-0.6%	-0.8%	-0.6%
CVVL	IATC	-0.70%	-0.70%	-0.5%	-0.5%	-0.5%	-0.6%
CVVL	MHEV	-0.40%	-0.40%	-0.4%	-0.2%	-0.4%	-0.7%
CVVL	IACC2	-0.90%	-0.90%	-0.7%	-0.6%	-0.7%	-0.8%
CVVL	8SPD	-0.80%	-0.80%	-0.8%	-0.6%	-0.8%	-0.6%
DEACD	IATC	-0.10%	-0.10%	-0.2%	-0.3%	-0.2%	-0.1%
DEACO	IATC	-0.10%	-0.10%	-0.6%	-0.1%	-0.6%	-0.1%
DEACO	MHEV	-0.40%	-0.40%	-0.4%	-0.2%	-0.4%	-0.7%
DEACO	IACC1	0.0%	0.0%	-0.5%	0.0%	-0.5%	0.0%
DEACO	IACC2	-0.90%	-0.90%	-1.0%	-0.6%	-1.0%	-0.8%
DEACO	8SPD	-0.80%	-0.80%	-0.8%	-0.6%	-0.8%	-0.6%
VVA	IATC	-0.70%	-0.70%	-0.6%	-0.4%	-0.6%	-0.6%
VVA	SHFTOPT	-0.80%	-0.80%	-0.8%	-0.6%	-0.8%	-0.7%
VVA	IACC1	-0.40%	-0.40%	-0.1%	-0.3%	-0.1%	-0.4%
VVA	IACC2	-0.80%	-0.80%	-1.0%	-0.5%	-1.0%	-0.6%
TRBDS1_SD	IATC	-0.50%	-0.50%	-0.5%	-0.5%	-0.5%	-0.5%
TRBDS1_MD	IATC	-0.50%	-0.50%	-0.5%	-0.5%	-0.5%	-0.5%
TRBDS1_LD	IATC	-0.50%	-0.50%	-0.5%	-0.5%	-0.5%	-0.5%
TRBDS1_SD	SHFTOPT	-0.10%	-0.10%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS1_MD	SHFTOPT	-0.10%	-0.10%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS1_LD	SHFTOPT	-0.10%	-0.10%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS1_SD	8SPD	-0.40%	-0.40%	-0.4%	-0.4%	-0.4%	-0.4%
TRBDS1_MD	8SPD	-0.40%	-0.40%	-0.4%	-0.4%	-0.4%	-0.4%
TRBDS1_LD	8SPD	-0.40%	-0.40%	-0.4%	-0.4%	-0.4%	-0.4%
TRBDS1_SD	MHEV	-0.60%	-0.60%	-0.2%	-0.1%	-0.2%	-0.6%
TRBDS1_MD	MHEV	-0.60%	-0.60%	-0.2%	-0.1%	-0.2%	-0.6%
TRBDS1_LD	MHEV	-0.60%	-0.60%	-0.2%	-0.1%	-0.2%	-0.6%
TRBDS1_SD	IACC2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRBDS1_MD	IACC2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRBDS1_LD	IACC2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TRBDS2_SD	NAUTO	-0.50%	-0.50%	-0.5%	-0.2%	-0.5%	-0.5%
TRBDS2_MD	NAUTO	-0.50%	-0.50%	-0.5%	-0.2%	-0.5%	-0.5%

Table V-21d Synergy pairings and values

		Fuel Consumption Improvement Synergy values by Vehicle Class Positive values are [positive] synergies, negative values are dissynergies. Blank cells are assumed to be zero.					
Technology A	**Technology B**	**Large PC**	**Large Perf. PC**	**Minivan LT**	**Small LT**	**Midsize LT**	**Large LT**
TRBDS2_LD	NAUTO	-0.50%	-0.50%	-0.5%	-0.2%	-0.5%	-0.5%
TRBDS2_SD	EPS	-0.30%	-0.30%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS2_MD	EPS	-0.30%	-0.30%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS2_LD	EPS	-0.30%	-0.30%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS2_SD	IACC2	-0.50%	-0.50%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS2_MD	IACC2	-0.50%	-0.50%	-0.3%	-0.3%	-0.3%	-0.3%
TRBDS2_LD	IACC2	-0.50%	-0.50%	-0.3%	-0.3%	-0.3%	-0.3%
CEGR1_SD	IACC2	-0.20%	-0.20%	0.0%	0.0%	0.0%	0.0%
CEGR1_MD	IACC2	-0.20%	-0.20%	0.0%	0.0%	0.0%	0.0%
CEGR1_LD	IACC2	-0.20%	-0.20%	0.0%	0.0%	0.0%	0.0%
CEGR2_SD	NAUTO	-0.60%	-0.60%	-0.8%	-0.6%	-0.8%	-0.8%
CEGR2_MD	NAUTO	-0.60%	-0.60%	-0.8%	-0.6%	-0.8%	-0.8%
CEGR2_LD	NAUTO	-0.60%	-0.60%	-0.8%	-0.6%	-0.8%	-0.8%
DCT	MHEV	-0.30%	-0.30%	0.0%	-0.3%	0.0%	0.0%
SHFTOPT	MHEV	-0.30%	-0.30%	-0.3%	-0.3%	-0.3%	-0.3%
ROLL1	AERO1	0.20%	0.20%	0.2%	0.2%	0.2%	0.1%
ROLL2	AERO2	0.10%	0.10%	0.3%	0.2%	0.3%	0.2%
MR1	VVA	0.20%	0.20%	-0.1%	0.0%	-0.1%	0.4%
MR1	DCP	0.20%	0.20%	-0.1%	0.0%	-0.1%	0.4%
MR1	CCPS	0.20%	0.20%	-0.1%	0.0%	-0.1%	0.4%
MR2	ROLL1	0.0%	0.0%	0.0%	0.1%	0.0%	-0.1%
MR4	TRBDS1_SD	0.0%	0.0%	0.3%	0.3%	0.3%	0.6%
MR4	TRBDS1_MD	0.0%	0.0%	0.3%	0.3%	0.3%	0.6%
MR4	TRBDS1_LD	0.0%	0.0%	0.3%	0.3%	0.3%	0.6%
MR4	AERO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
MR5	ROLL1	0.0%	0.0%	0.4%	0.5%	0.4%	0.4%
ADSL_SD	IATC	1.2%	1.2%	0.8%	1.0%	0.8%	1.0%
ADSL_MD	IATC	1.2%	1.2%	0.8%	1.0%	0.8%	1.0%
ADSL_LD	IATC	1.2%	1.2%	0.8%	1.0%	0.8%	1.0%
NAUTO	SAX	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%	-0.40%
SHEV1	AERO2	1.4%	1.4%	1.4%	1.3%	1.4%	1.4%
SHEV1	ROLL1	0.8%	0.8%	0.9%	0.8%	0.9%	1.1%
SHEV1	MR2	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%	-0.4%
SHEV1	MR3	-0.2%	-0.2%	-0.1%	-0.2%	-0.1%	-0.1%
SHEV1	MR4	-0.2%	-0.2%	-0.2%	-0.1%	-0.2%	-0.2%
SHEV1	MR5	0.0%	0.0%	-0.2%	-0.2%	-0.2%	-0.2%
SHEV1_2	AERO2	0.0%	0.0%	-0.1%	0.0%	-0.1%	-0.1%
SHEV1_2	ROLL2	0.9%	0.9%	0.7%	0.80%	0.7%	0.7%
SHEV1_2	MR2	0.0%	0.0%	0.2%	0.0%	0.2%	0.0%
SHEV1_2	MR3	-0.1%	-0.1%	-0.1%	0.0%	-0.1%	-0.1%
SHEV1_2	MR4	-0.1%	-0.1%	-0.1%	-0.2%	-0.1%	0.0%
SHEV1_2	MR5	0.0%	0.0%	-0.1%	-0.1%	-0.1%	0.0%
SHEV2	AERO2	1.4%	1.4%	1.3%	1.3%	1.3%	1.3%
SHEV2	ROLL2	1.7%	1.7%	1.6%	1.6%	1.6%	1.8%
SHEV2	MR2	-0.4%	-0.4%	-0.2%	-0.4%	-0.2%	-0.4%
SHEV2	MR3	-0.3%	-0.3%	-0.2%	-0.2%	-0.2%	-0.2%
SHEV2	MR4	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.2%
SHEV2	MR5	0.0%	0.0%	-0.3%	-0.3%	-0.3%	-0.2%
PHEV1	AERO2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PHEV1	ROLL2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

How much does the technology cost?

Direct Cost Estimates

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 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).[137] This report was peer reviewed by experts in the industry and revised by FEV in response to the peer review comments.[138] 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.[139]

Since then, FEV's work under this contract work assignment has continued. Additional cost studies have been completed and are available for public review.[140] 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

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[137] 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 No. NHTSA-2010-0131

[138] U.S. EPA, "Light-Duty Technology Cost Analysis Pilot Study Peer Review Report —Response to Comments Document", December 21, 2009, Docket No. NHTSA-2010-0131

[139] U.S. EPA, "Light-duty Technology Cost Analysis – Report on Additional Case Studies," Docket No. NHTSA-2010-0131

[140] 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, Docket No. NHTSA-2010-0131

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. This HEV cost work, including the extension of results to P2 HEVs, has been extensively documented in a new report prepared by FEV.[141] Because of the complexity and comprehensive scope of this HEV analysis, EPA commissioned a separate peer review focused exclusively on it. Reviewer comments generally supported FEV's methodology and results, while including a number of suggestions for improvement which were subsequently incorporated into FEV's analysis and final report. The peer review comments and responses are available in the rulemaking docket.[142] [143]

Over the course of this entire work assignment, teardown-based studies were performed on each of 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). As explained, the results from this tear-down were extended to address P2 hybrids. In addition, costs from individual components in this tear-down study were also 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. (As stated previously, this technology is not included as an enabling technology in this analysis, although it is included as a baseline technology because it exists in the 2008 baseline fleet).
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 of the uncertainty related to industry-wide use due to potential intellectual property issues.)

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[141] 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 No. NHTSA-2010-0131

[142] 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, Docket No. NHTSA-2010-0131

[143] FEV, Inc. and U.S. 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, Docket No. NHTSA-2010-0131

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

1. Downsizing a SOHC 2 valve/cylinder V8 engine to a DOHC V6.
2. Downsizing a DOHC V8 to a DOHC V6.
3. Downsizing a SOHC V6 engine to a DOHC 4 cylinder engine.
4. 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 each 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 (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[144] if technologies are introduced too rapidly for some indirect costs to be fully recovered. 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).

It is difficult to quantify accurately any capital stranding associated with new technology phase-ins under the proposed 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. 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, in order to account for the possibility of stranded capital costs, the agencies asked FEV to perform a separate analysis of potential stranded capital costs associated with rapid phase-in of select technologies that FEV had already torn down, using data from FEV’s primary teardown-based cost analyses. Detailed information on how FEV performed this exercise and the results of this exercise can be found in Section 3.2.2.3 of Chapter 3 of the draft joint TSD, and we refer readers there for more information.

DOT has modified the CAFE model, if specified for a given technology, when that technology is replaced by a newly applied technology, to apply a stream of costs representing the stranded capital cost of the replaced technology. This cost is in addition to the cost for producing the newly-applied technology. Because FEV assumed a ten year production life, for capital depreciation, any time a technology evaluated by FEV is replaced before its tenth year of being production, there is the potential for the stranding of capital. To account for this, the model determines how long a technology has been applied by the model. If a technology has been applied by the model for ten years or longer, the model does not apply these additional stranded capital costs when or if that technology gets replaced. However, if a technology is being replaced only five years after it was first applied by the model, then the model applies a stranded capital cost. FEV derived stranded capital costs for situations where a technology is replaced after three, five and eight years of production. FEV also assumed that for each of those years, the stranded capital would be recouped over a five year period. NHTSA extrapolated the FEV values to create a lookup table, Table V-22 below, which defines the stranded capital costs from

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[144] The potential for stranded capital occurs when manufacturing equipment and facilities cannot be used in the production of a new technology.

years one through ten. For example, if a 6-speed DCT (DCT) is replaced by an 8-speed transmission (8SPD) 8 years after it was first applied, then the model will apply a cost of penalty of $7.96 to the 8SPD technology for 5 years.

For some of the technologies, NHTSA's inputs, which are designed to be as consistent as practicable with EPA's, indicate negative incremental costs. In other words, the agency is estimating that some technologies, if applied in a manner that holds performance and utility constant, will, following initial investment (for, *e.g.*, R&D and tooling) by the manufacturer and its suppliers, incrementally improve fuel savings and reduce vehicle costs. Nonetheless, in the agency's central analysis, these and other technologies are applied only insofar as is necessary to achieve compliance with standards defining any given regulatory alternative (where the baseline no action alternative assumes CAFE standards are held constant after MY2016). The agency has also performed a sensitivity analysis involving market-based application of technology—that is, the application of technology beyond the point needed to achieve compliance, if the cost of the technology is estimated to be sufficiently attractive relative to the accompanying fuel savings. NHTSA has invited comment on all of its technology estimates, and specifically requests comment on the likelihood that each technology will, if applied in a manner that holds vehicle performance and utility constant, be able to both deliver the estimated fuel savings and reduce vehicle cost. The agency also invites comment on whether, for the final rule, its central analysis should be revised to include estimated market-driven application of technology.

Table V-24 Stranded Capital Costs

		Stranded Capital Cost Table									
Technology	**Abbr.**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Low Friction Lubricants - Level 1	LUB1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Engine Friction Reduction - Level 1	EFR1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cylinder Deactivation on SOHC	DEACS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Continuously Variable Valve Lift (CVVL)	CVVL	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cylinder Deactivation on DOHC	DEACD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cylinder Deactivation on OHV	DEACO	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Variable Valve Actuation - CCP and DVVL on OHV	VVA	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	TRBDS1_SD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	TRBDS1_MD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	TRBDS1_LD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	TRBDS2_SD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	TRBDS2_MD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	TRBDS2_LD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	$72.65	$64.51	$56.37	$48.32	$40.26	$32.21	$24.16	$16.11	$8.06	$ -
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Advanced Diesel - Small Displacement	ADSL_SD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Advanced Diesel - Medium Displacement	ADSL_MD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Advanced Diesel - Large Displacement	ADSL_LD	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6-Speed Manual/Improved Internals	6MAN	$35.82	$31.84	$27.86	$23.88	$19.90	$15.92	$11.94	$7.96	$3.98	$ -
High Efficiency Gearbox (Manual)	HETRANSM	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Improved Auto. Trans. Controls/Externals	IATC	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6-Speed Trans with Improved Internals (Auto)	NAUTO	$79.19	$66.94	$54.68	$46.87	$39.06	$31.25	$23.43	$15.62	$7.81	$ -

6-speed DCT	DCT	$35.82	$31.84	$27.86	$23.88	$19.90	$15.92	$11.94	$7.96	$3.98	$ -
8-Speed Trans (Auto or DCT)	8SPD	$35.82	$31.84	$27.86	$23.88	$19.90	$15.92	$11.94	$7.96	$3.98	$ -
High Efficiency Gearbox (Auto or DCT)	HETRANS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Shift Optimizer	SHFTOPT	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Power Steering	EPS	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Improved Accessories - Level 1	IACC1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	IACC2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
12V Micro-Hybrid (Stop-Start)	MHEV	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Integrated Starter Generator	ISG	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Strong Hybrid - Level 1	SHEV1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Conversion from SHEV1 to SHEV2	SHEV1_2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Strong Hybrid - Level 2	SHEV2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Plug-in Hybrid - 30 mi range	PHEV1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Plug-in Hybrid	PHEV2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Early Adopter) - 100 mile range	EV2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Early Adopter) - 150 mile range	EV3	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Electric Vehicle (Broad Market) - 150 mile range	EV4	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Fuel Cell Vehicle	FCV	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 1	MR1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 2	MR2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 3	MR3	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 4	MR4	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass Reduction - Level 5	MR5	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Rolling Resistance Tires - Level 1	ROLL1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Rolling Resistance Tires - Level 2	ROLL2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Rolling Resistance Tires - Level 3	ROLL3	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Low Drag Brakes	LDB	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Secondary Axle Disconnect	SAX	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Aero Drag Reduction, Level 1	AERO1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Aero Drag Reduction, Level 2	AERO2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

Learning Curves

The agency uses learning curves to account for the cost reductions that manufacturers realize through experiential learning achieved through applying technologies. A complete discussion on the development and application of learning curves can be found in Chapter VII of this PRIA.

Indirect Cost Multiplier

Indirect costs were accounted for through the application of Indirect Cost Multipliers (ICMs), which were created by EPA. ICMs were applied to each technology's year-by-year direct cost to arrive at its total compliance cost, which are the costs used for modeling purposes. A full discussion of the development and application of the ICMs for purposes of this analysis can be found in Chapter VII of this PRIA.

What specific technologies did NHTSA considered for application in this rulemaking, and what are NHTSA's estimates of their incremental costs and effectiveness?

ICE Engine Technologies

What is an Internal Combustion Engine (ICE)?

Most passenger cars and light trucks in the U.S. have gasoline-fueled spark ignition internal combustion engines. These engines move the vehicle by converting the chemical energy in gasoline fuel to useful mechanical work output as shaft torque and power delivered to the transmission and to the vehicle' s driving wheels. Vehicle fuel economy is directly proportional to the efficiency of the engine. Two common terms are used to define the efficiency of an engine are (1) Brake Specific Fuel Consumption (BSFC), which is the ratio of the mass of fuel used to the output mechanical energy; and (2) Brake Thermal Efficiency (BTE), which is the ratio of the fuel chemical energy, known as calorific value, to the output mechanical energy.

The efficiency of an automotive spark ignition engine varies considerably with the rotational speed and torque output demanded from the engine. The most efficient operating condition for most current engine designs occurs around medium speed (30-50 percent of the maximum allowable engine rpm) and typically between 70-85 percent of maximum torque output at that speed. At this operating condition, BTE is typically 33-36 percent. However, at lower engine speeds and torque outputs, at which the engine operates in most consumer vehicle use and on standardized drive cycles, BTE typically drops to 20-25 percent.

Spark ignition engine efficiency can be improved by reducing the energy losses that occur between the point of combustion of the fuel in the cylinders to the point where that energy reaches the output crankshaft. Reduction in this energy loss results in a greater proportion of the chemical energy of the fuel being converted into useful work. For improving engine efficiency at lighter engine load demand points, which are most relevant for CAFE fuel economy, the technologies that can be added to a given engine may be characterized by which type of energy loss is reduced. The main types of energy losses that can be reduced in gasoline engines to improve fuel economy are exhaust energy losses, engine friction losses, and gas exchange losses. Converting the gasoline engine to a diesel engine can also reduce heat losses.

How can ICE efficiency be improved?

Exhaust Energy Loss Reduction

Exhaust energy includes the kinematic and thermal energy of the exhaust gases, as well as the wasted chemical energy of unburned fuel. These losses represent approximately 32 percent of the initial fuel chemical energy and can be reduced in three ways: first, by recovering mechanical or electrical energy from the exhaust gases; second, by improving the hydrocarbon fuel conversion; and third, by improving the cycle thermodynamic efficiency. The thermodynamic efficiency can be improved by either increasing the engine's compression ratio or by operating with a lean air/fuel ratio.

Engine Friction Loss Reduction

Friction losses can represent a significant proportion of the global losses at low load. These losses are dissipated through the cooling system in the form of heat. Besides via direct reduction measures, friction can also be reduced through downsizing the engine by means of increasing the engine-specific power output.

Gas Exchange Loss Reduction

The energy expended while delivering the combustion air to the cylinders and expelling the combustion products is known as gas exchange loss, commonly referred to as pumping loss. The main source of pumping loss in a gasoline engine is the use of an inlet air throttle, which regulates engine output by controlling the pre-combustion cylinder air pressure, but which is an inefficient way to achieve this pressure control. A more efficient way of controlling the cylinder air pressure is to modify the valve timing or lift. Another way to reduce the average pumping losses is to "downsize" the engine, making it run at higher loads or higher pressures.
Several different technologies target pumping loss reduction, but the fuel consumption reduction from these technologies is not necessarily cumulative. Once most of the pumping work has been eliminated, adding further technologies that also target reduced pumping loss will have little additional effectiveness. Thus, in the decision trees used for this analysis, the effectiveness value shown for additional technologies targeting pumping loss depends on the existing technology combination already present on the engine.

What technologies can improve fuel efficiency for both gasoline and diesel ICEs?

Low Friction Lubricants (LUB)

One of the most basic methods of reducing fuel consumption in gasoline engines is the use of lower viscosity engine lubricants. More advanced multi-viscosity engine oils are available today with improved performance in a wider temperature band and with better lubricating properties. This can be 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 even 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, rod and main bearings and changes to the mechanical tolerances of engine components may be required. In all cases, durability testing would be required to ensure that durability is not compromised. The shift to lower viscosity and lower friction lubricants will also improve the effectiveness of valvetrain technologies such as cylinder deactivation, 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 proposal, the agencies relied on the lumped parameter model and determined that the range for the effectiveness of low friction lubricant is 0.5 to 0.8 percent.

In the 2012-2016 rule, the 2010 TAR and the recent HD GHG 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 have updated it to $3 (2009$) for this analysis[145]. No learning is applied to this technology, so the DMC remains $3 year-over-year. The agencies have used a low complexity short-term ICM of 1.24 for this technology through 2018, and a long-term ICM of 1.19 thereafter. The resultant costs are shown in Table V-25.[146]

Table V-25 Costs for Engine Modifications to Accommodate Low Friction Lubes (2009$)

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 engine.

Engine Friction Reduction Level I and II (EFR1and LUB2_EFR2)

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.[147] Examples include improvements in 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, and minute improvements in several components can add up to a 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 to be between 1 to 3 percent. Because of the

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[145] The cost was updated to 2009$. However, due to rounding to the whole dollar amount it still $3.

[146] 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.

[147] "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.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA508227 (last accessed November 13, 2011)

incremental nature of the CAFE model, NHTSA used the narrower range of 1 to 2 percent, which resulted in an average effectiveness of 1.5 percent. For this rulemaking analysis, based on the 2011 Ricardo study, the effectiveness for engine friction reduction range has been increased to 2.0 to 2.7 percent incremental to low friction lubricant 1 (LUB1).

Additionally, for this proposal, the agencies have added a second level of incremental improvements in low friction lubricants and engine friction reduction (LUB2_EFR2). This LUB2_EFR2 includes some additional effectiveness improvements to low friction lubricant, relative to the low friction lubricant technology discussed above, based on assumptions based on manufacturer statements that further improvements will be made to low friction lubricants. The technologies for this second level of engine friction reduction and low friction lubricants are considered to be available for purposes of this analysis 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. However, because of the incremental nature 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 (EFR1) and low friction lubricants (LUB1).

In the 2012-2016 rule, the 2010 TAR and the HD GHG final rule, NHTSA and EPA used a cost estimate of $11.71 (2007$) per cylinder as the direct manufacturing cost for EFR1, which is $12 (updated to 2009$) per cylinder in this analysis. No learning is applied to this technology, so the DMC remains $12 (2009$) year-over-year. The agencies have used a low complexity ICM of 1.24 for this technology through 2018 and a long-term ICM of 1.19 thereafter. The resultant costs are shown in

Table V-26.

Table V-26 Costs for Engine Friction Reduction – Level 1 (EFR1) (2009$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	I3	$35	$35	$35	$35	$35	$35	$35	$35	$35
DMC	I4	$47	$47	$47	$47	$47	$47	$47	$47	$47
DMC	V6	$70	$70	$70	$70	$70	$70	$70	$70	$70
DMC	V8	$93	$93	$93	$93	$93	$93	$93	$93	$93
IC	I3	$8	$8	$7	$7	$7	$7	$7	$7	$7
IC	I4	$11	$11	$9	$9	$9	$9	$9	$9	$9
IC	V6	$17	$17	$13	$13	$13	$13	$13	$13	$13
IC	V8	$23	$23	$18	$18	$18	$18	$18	$18	$18
TC	I3	$44	$44	$42	$42	$42	$42	$42	$42	$42
TC	I4	$58	$58	$56	$56	$56	$56	$56	$56	$56
TC	V6	$87	$87	$84	$84	$84	$84	$84	$84	$84
TC	V8	$116	$116	$111	$111	$111	$111	$111	$111	$111

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline engine.

The agencies have estimated the DMC for the second level of friction reduction with a second level of low friction lube as double the combined DMCs of the first level of engine friction reduction and first level of low friction lube (that is, double the DMC relative to the baseline). The resultant costs of LUB2_EFR2 are as shown in

Table V-27. For LUB2_EFR2 the agencies have used a low complexity ICM of 1.24 through 2024 and a long-term ICM of 1.19 thereafter.

Table V-27 Costs for Engine Friction Reduction – Level 2(LUB2_EFR2) (2009$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	I3	$76	$76	$76	$76	$76	$76	$76	$76	$76
DMC	I4	$100	$100	$100	$100	$100	$100	$100	$100	$100
DMC	V6	$146	$146	$146	$146	$146	$146	$146	$146	$146
DMC	V8	$193	$193	$193	$193	$193	$193	$193	$193	$193
IC	I3	$18	$18	$18	$18	$18	$18	$18	$18	$15
IC	I4	$24	$24	$24	$24	$24	$24	$24	$24	$19
IC	V6	$35	$35	$35	$35	$35	$35	$35	$35	$28
IC	V8	$47	$47	$47	$47	$47	$47	$47	$47	$37
TC	I3	$95	$95	$95	$95	$95	$95	$95	$95	$91
TC	I4	$124	$124	$124	$124	$124	$124	$124	$124	$119
TC	V6	$182	$182	$182	$182	$182	$182	$182	$182	$175
TC	V8	$240	$240	$240	$240	$240	$240	$240	$240	$230

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

Gasoline Engine Technologies

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 2010, approximately 86 percent of all new cars and light trucks had engines with some method of variable valve timing.[148] Manufacturers are currently using many different types of variable valve timing, which have a

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[148] "Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends - 1975 through 2009", EPA420-S-07-001, September 2007, Docket No. NHTSA-2010-0131. Available at http://www.epa.gov/oms/cert/mpg/fetrends/fetrends-archive.htm (last accessed November 13, 2011).

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 baseline vehicle fleet file is used to determine the degree to which VVT technologies have already been applied to particular vehicles, to ensure that the proper level of VVT technology, if any, is applied.

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. The three major types of VVT are listed below.

Intake Cam Phasing (ICP)

Valvetrains with 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 TAR, NHTSA and EPA assumed an effectiveness range of 2 to 3 percent for ICP. Based on the 2011 Ricardo study and updated lumped-parameter model the agencies have fine-tuned the range to 2.1 to 2.7 percent.

In the 2012-2016 rule and the 2010 TAR, the agencies estimated the DMC of a cam phaser needed for ICP at $37 (2007$). This DMC becomes $38 (2009$) for this analysis and is considered applicable in the 2015 MY. This cost would be required for each cam shaft controlling intake valves; an overhead cam I4 would need one phaser, an overhead cam V6 or V8 would need two phasers, and an overhead valve V6 or V8 would need just one. 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 a long-term ICM of 1.19 thereafter. The resultant costs are shown in

Table V-28.

Table V-28 Costs for Intake Cam Phasing (2009$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	OHC-I4	$36	$36	$35	$34	$34	$33	$32	$32	$31
DMC	OHC-V6/V8	$73	$71	$70	$68	$67	$66	$64	$63	$62
DMC	OHV-V6/V8	$36	$36	$35	$34	$34	$33	$32	$32	$31

IC	OHC-I4	$9	$9	$7	$7	$7	$7	$7	$7	$7
IC	OHC-V6/V8	$18	$18	$15	$15	$15	$15	$15	$15	$15
IC	OHV-V6/V8	$9	$9	$7	$7	$7	$7	$7	$7	$7
TC	OHC-I4	$46	$45	$42	$42	$41	$40	$40	$39	$38
TC	OHC-V6/V8	$91	$90	$84	$83	$82	$80	$79	$78	$76
TC	OHV-V6/V8	$46	$45	$42	$42	$41	$40	$40	$39	$38

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; OHC=overhead cam; OHV=overhead valve; all costs are incremental to the baseline.

Coupled Cam Phasing (CCPS and CCPO)

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 overhead cam 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 overhead valve (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.[149]

The analysis for MYs 2012-2016 final rule used an effectiveness estimate for CCP of between 1 to 4 percent. Due to the incremental nature and decision tree logic of the Volpe model, NHTSA estimated the effectiveness for coupled cam phasing on a SOHC engine to be 1 to 3 percent and 1 to 1.5 percent for coupled cam phasing on an overhead valve engine.

For this proposal, the agencies, taking into account the additional review and the work performed for the 2011 Ricardo study, have revised the estimates for CCP. 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, which represents an increase over the estimates used in 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). VVA is discussed later in this chapter..

The same cam phaser has been assumed for intake cam phasing as for coupled cam phasing, thus CCP cost estimates are identical to those presented in

Table V-28.

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[149] We note that coaxial camshaft developments would allow other VVT options to be applied to OHV engines. However, since they would potentially be adopted on only a limited number of OHV engines, because of the complexity of these systems, NHTSA did not include them in the decision tree for this analysis.

Dual Cam Phasing (DCP)

The most flexible VVT design is dual (independent) cam phasing, 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. Increased internal EGR also results in lower engine-out NO_X emissions. The amount by which fuel consumption is improved depends 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 the 2012-2016 final rule and TAR, the agencies assumed an effectiveness range for DCP of between 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 4.1 to 5.5 percent relative to a base engine, or 2.0 to 2.7 percent relative to an engine with ICP.

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, an overhead cam I4 would need two phasers, an overhead cam V6 or V8 would need four phasers, and an overhead valve V6 or V8 would need two. NHTSA believes that with DCP the exhaust valves can be closed earlier to allow some in-cylinder EGR, so we subtracted the cost of an EGR valve per bank for DCP. The EGR valve cost is $6 (2007$) in MY 2012, so the DCP cost per bank is $31 (2007$). Converting to 2009$, the DCP cost is $33. 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 V-29.

Table V-29 Costs Per Cylinder Bank for VVT-Dual Cam Phasing (2009$)

Index	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$31	$30	$30	$29	$29	$28	$27	$27	$26
IC	$13	$13	$9	$9	$9	$9	$9	$9	$9
TC	$44	$43	$39	$38	$38	$37	$37	$36	$36
DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to base engine.									

Variable Valve Lift (VVL)

Controlling the lift of the valves provides an opportunity 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 for most of the fleet. There are two major classifications of variable valve lift, as described below:

Discrete Variable Valve Lift (DVVLS, DVVLD, DVVLO)

Discrete variable valve lift (DVVL) systems allow the selection between two or three discrete cam profiles by means of a hydraulically-actuated mechanical system. By optimizing the cam 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. This increases the efficiency of the engine. 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.

In the MY 2012-16 final rule, based on previously-received confidential manufacturer data and the report from NESCCAF, the agencies estimated the effectiveness of DVVL to be between 1 to 4 percent above that realized by VVT systems. Based on 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 for purposes of this analysis.

In the 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. These DMCs become $120 (2009$), $174 (2009$) and $248 (2009$) or $30, $29 and $31 per cylinder for this analysis, all of which are considered applicable in MY 2015. Because the CAFE model uses cost per cylinder for this technology, NHTSA averaged the cost per cylinder for 4, 6 and 8 cylinder engines into a cost of $30 (2009$) per cylinder for application in the CAFE model. 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 a long-term ICM of 1.29 thereafter. The resultant costs are shown in

Table V-30.

Table V-30 Costs Per Cylinder for Discrete Variable Valve Lift (2009$)

Index	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$29	$28	$27	$27	$26	$26	$25	$25	$24
IC	$12	$12	$9	$9	$9	$9	$9	$9	$9
TC	$40	$39	$36	$35	$35	$34	$34	$33	$33

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to base engine.

Continuously Variable 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.

In the MYs 2012-2016 final rule, the agencies 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” engines. For this rulemaking, NHTSA has increased the incremental effectiveness values for this technology, based on the updated LPM, 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 MYs 2012-2016 rule and the 2010 TAR, the agencies estimated the DMC of CVVL at $174 (2007$), $320 (2007$) and $349 (2007$) for an OHC-I4, OHC-V6 and OHC-V8 engine, respectively. These DMCs become $180 (2009$), $330 (2009$) and $360 (2009$), or $45, $55 and $45 per cylinder for this analysis, all of which are considered applicable in MY 2015. Because the CAFE model uses cost per cylinder for this technology, NHTSA averaged the cost per cylinder for 4, 6 and 8 cylinder engines into a cost of $48 (2009$) per cylinder for application in the CAFE model. 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 a long-term ICM of 1.29 thereafter. The resultant costs are shown in Table V-31.

Table V-31 Costs per Cylinder for Continuous Variable Valve Lift (2009$)

Index	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$46	$45	$44	$43	$42	$42	$41	$40	$39
IC	$19	$19	$14	$14	$14	$14	$14	$14	$14
TC	$65	$64	$58	$57	$56	$55	$54	$54	$53
DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to base engine.									

Variable Valve Actuation (VVA)

For this proposal, NHTSA has combined two valve control technologies for OHV engines; specifically, coupled cam phasing (CCPO) and discrete valve lift (DVVLO) have been combined into one technology, designated as variable valve actuation (VVA). The agency estimates the incremental effectiveness for VVA applied to an 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). The cost for VVA is equal to the costs of CCPO and DVVLO together. However, since DEACO precedes VVA and includes the cost for lost motion devices, which enables DVVL, there is no additional cost for DVVL thus the VVA cost is equal to the CCPO cost.

Table V-32 Costs per Cylinder for Variable Valve Actuation (2009$)

Index	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$36	$36	$35	$34	$34	$33	$32	$32	$31
IC	$15	$15	$11	$11	$11	$11	$11	$11	$11
TC	$51	$50	$46	$45	$44	$44	$43	$42	$42
DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to base engine.									

Cylinder Deactivation (DEACS, DEACD, DEACO)

In conventional spark-ignited engines, throttling the 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 – the valves are kept closed, and no fuel is injected – 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. 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 within which it can deactivate the cylinders. Noise and vibration issues can reduce the operating range to which 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 cancellations systems to address NVH concerns and to allow a greater operating range of activation (and the agencies have estimated the costs for doing so, as noted below). Manufacturers have legitimately stated that use of DEAC on 4 cylinder engines would cause unacceptable NVH; therefore, as in the 2012-2016 rule and the TAR, the agencies are not applying cylinder deactivation to 4-cylinder engines in evaluating potential emission reductions/fuel economy improvements and attendant 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 lineups. Honda also offers V6 models (Odyssey, Pilot) 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 effectiveness estimates from the 2012-2016 final rule, TAR, and the FRIA for the heavy-duty GHG and fuel consumption rule. Previous estimates ranged from a 6 percent reduction in CO_2 emissions depending on vehicle class for the OMEGA model, which uses technology packages. The following ranges were used in the CAFE model, due to its incremental nature, depending on the engine valvetrain configuration: for DOHC engines which are already equipped with DCP and DVVLD, only up to 0.5 percent for DEACD; for SOHC engines which have CCP and DVVLS applied, from 2.5 to 3 percent for DEACS; and for OHV engines, without VVT or VVL technologies, from 3.9 to 5.5 percent for DEACO.

For this proposal, the agencies, taking into account the additional review and the work performed for the Ricardo study, have revised the estimates for cylinder deactivation. The effectiveness for relative to the base engine is 4.7 to 6.5 percent based on the lumped parameter model. Because of the incremental nature of the CAFE model, NHTSA used the effectiveness range of 0.44 to 0.66 percent incremental for SOHC and DOHC applications, and for OHV applications, the effectiveness was increased slightly with a range of 4.66 to 6.30 percent.

In the 2012-2016 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. The DMCs become $144 (2009$) and $162 (2009$) 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 a long-term ICM of 1.19 thereafter. The resultant costs are shown in

Table V-33.

Table V-33 Costs for Cylinder Deactivation (2009$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	V6	$137	$134	$131	$129	$126	$124	$121	$119	$116
DMC	V8	$154	$151	$148	$145	$142	$139	$136	$134	$131
IC	V6	$55	$55	$41	$41	$41	$41	$41	$41	$41
IC	V8	$62	$62	$46	$46	$46	$46	$46	$46	$46
TC	V6	$192	$189	$173	$170	$167	$165	$162	$160	$157
TC	V8	$216	$213	$194	$191	$188	$185	$182	$180	$177

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

If lost motion devices are on the engine from the application of DVVL, the cost of DEACS and DEACD, for SOHC and DOHC engines respectively, would be $32 in MY 2017. This $32 accounts for the potential additional application of active engine mounts on SOHC and DOHC engines.[150] Further, this SOHC and DOHC engine estimate is relevant to the CAFE model only,

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[150] The $32 cost for active engine mounts comes from the $75 (RPE) estimate used in the MY 2011 final rule that was then adjusted to account for the use of the ICM instead of the RPE. The cost is then divided by two due to the assumption that only half the applications would require active engine mounts to meet NVH targets.

because the OMEGA model does not apply technologies in the same incremental fashion as the CAFE model.

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 (Lexus IS 350), Ford (Ecoboost), and General Motors (Chevrolet Impala and Cadillac CTS 3.6L). BMW, GM, Ford and VW/Audi have announced plans to increase dramatically the number of SGDI engines in their portfolios.

NHTSA and EPA reviewed effectiveness estimates from the 2012-2016 final rule and TAR, which employed an effectiveness range for SGDI of 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 5.8 percent. NHTSA and EPA also reviewed other published literature reporting 3 percent effectiveness for SGDI.[151] Confidential manufacturer data reported an efficiency effectiveness range of 1 to 2 percent. Based on data from the recent Ricardo study and reconfiguration of the new lumped parameter model, EPA and NHTSA have revised this value to 1.5 percent[152]. 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 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,

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[151] 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 No. NHTSA-2010-0131. Available at http://www.erc.wisc.edu/symposiums/2005_Symposium/June%208%20PM/Whitaker_Ricardo.pdf (last accessed Nov. 4, 2011).

[152] 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.

specifically from the injectors and the fuel lines and have included corresponding cost estimates for these NVH controls. In the 2012-2016 final rule analysis, the agencies estimated the DMC for SGDI at $213 (2007$), $321 (2007$) and $386 (2007$) for I3/I4, V6 and V8 engines, respectively. These DMCs become $220 (2009$), $331 (2009$) and $398 (updated to 2009$) or $55, $55 and $50 per cylinder for this analysis, all of which are considered applicable in MY 2012. Because the CAFE model uses cost per cylinder for this technology, NHTSA averaged the cost per cylinder for 4, 6 and 8 cylinder engines into a cost of $53 (2009$) per cylinder for application in the CAFE model. 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 a long-term ICM of 1.29 thereafter. The resultant costs are shown in

Table V-34.

Table V-34 Costs per Cylinder for Stoichiometric Gasoline Direct Injection (2009$)

Index	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$46	$45	$44	$44	$43	$42	$41	$40	$39
IC	$20	$20	$15	$15	$15	$15	$15	$15	$15
TC	$67	$66	$60	$59	$58	$57	$56	$55	$54
DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to base engine.									

Turbocharging and Downsizing (TRDBS)

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.

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. In order to provide adequate acceleration from standstill, particularly up grades or at high altitudes, 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). 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.[153]

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.[154] [155] [156] [157] [158] Confidential manufacturer data suggests an incremental range of fuel consumption reduction of 4.8 to 7.5 percent for turbocharging and downsizing. Other publicly-available sources suggest a fuel consumption 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 suggests a fuel economy gain of 8 to 10 percent is possible 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;[159] a Renault report suggests 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;[160] and a Robert Bosch paper suggests a 13 percent NEDC gain for downsizing to a turbocharged DI engine, again with

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[153] "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.

[154] Cairns et al., Lotus, "Low Cost Solutions for Improved Fuel Economy in Gasoline Engines," Global Powertrain Congress September 27-29, 2005, vol. 33. Available at http://www.gpc-icpem.org/pages/publications.html (last accessed March 15, 2010).

155 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, 2011).

156 "Interim Report: New Powertrain Technologies and Their Projected Costs," October 2005, EPA420-R-05-012. Docket NHTSA-2010-0131. Available at http://www.epa.gov/otaq/technology/420r05012.pdf (last accessed November 14, 2011)

157 "Cost and Fuel Economy Comparison of Diesel and Gasoline Powertrains in Passenger Cars and Light Trucks," submitted by FEV Engine Technology, Inc., April 23, 2003, contained as Appendix I within EPA Interim Technical Report EPA420-R-04-002. Docket N0o. NHTSA-2010-0131

158 "Electric Cars: Plugged In, Batteries must be included," Deutsche Bank Global Markets Research Company, June 9, 2008. Docket NHTSA-2010-0131 or Available at http://www.inrets.fr/fileadmin/recherche/transversal/pfi/PFI_VE/pdf/deutch_bank_electric_cars.pdf (last accessed November 14, 2011)

[159] 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)

[160] 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.

wall-guided injection.[161] [162] 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 assumed a 12 to 14 percent absolute effectiveness improvement, which included low friction lubricant (level one), engine friction reduction (level one), DCP, DVVL and SGDI, over a 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 agencies believe that the effectiveness of turbocharging and downsizing is highly dependent upon implementation and degree of downsizing.

Given these variances, for this proposal the agencies evaluated 4 different levels of downsized and turbocharged high Brake Mean Effective Pressure (BMEP)[163] engines: 18-bar (TRBDS1), 24-bar (TRBDS2), 24-bar with cooled exhaust gas recirculation (CEGR1), and 27-bar with cooled EGR (CEGR2). All engines are assumed to include gasoline direct injection (SGDI), and thus the effectiveness values for TRBDS include the benefits of this technology. In addition, the agencies believe that in order to implement in production a 27-bar level engine, it is necessary to incorporate cooled exhaust gas recirculation (EGR), and also to require a 2-stage turbocharger as well as engine changes to increase robustness of the engine to allow the engine to operate at these higher BMEP levels. The cooled EGR technology is discussed later in this section. To mitigate potential issues with launch performance for these highly downsized engines, NHTSA does not allow the application of 24- or 27-bar engines unless the vehicle utilizes an 8-speed automatic or DCT transmission or a 6-speed manual transmission. This requirement helps to ensure that the transmission's gear ratio spread can accommodate a lower first gear, a.k.a. "granny gear", to aid in launching the vehicle from a complete stop. Table V-35 lists the possible engine downsizing options that the agencies considered in this NPRM analysis.

Table V-35 Possible Engine Downsizing Options

Base Engine	18-bar Engine	24-bar Engine	27-bar Engine
I4	I4	I3	I3
V6	I4	I4	I4
V8+	V6	V6	I4

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

[162] NEDC is the New European Driving Cycle. It was created to represent the typical driving pattern in Europe and is used in the EU emission and fuel economy certification tests. The cycle consists of the old European driving cycle (ECE15) and an Extra-Urban driving cycle (EUDC)

[163] 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.

NHTSA and EPA have revised the effectiveness estimate for TRBDS to reflect the new Ricardo work, and now assume that turbocharging and downsizing, alone, will provide a 12 to 24.6 percent absolute effectiveness improvement (depending on the 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 as stated above was assumed to yield a 12 to 14 absolute effectiveness in the MYs 2012-2016 analysis, now results in a 16.8 to 20.9 percent absolute 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. Thus, these changes have contributed significantly to the agencies' ability to assume improvements in fuel economy during the rulemaking timeframe.

As noted above, the agencies relied on engine teardown analyses conducted by EPA, FEV and Munro to develop costs for turbocharged GDI engines.[164] Based on that work, in the 2012-2016 final rule, 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 engines represents twin turbochargers versus the single turbocharger in the I-configuration engine. Converting to 2009$, these DMCs become $417 and $702, respectively, for this analysis. For the higher BMEP engines, in the 2010 TAR, the agencies assumed costs for 24 bar BMEP turbocharging of 1.5x the cost of the 18 bar BMEP technology, and also assumed single stage turbo for these 24 bar BMEP engine. This additional cost covered the incremental cost increase of a variable geometry turbocharger (see 2010 TAR at page B-12). Using this methodology, the DMC for 24 bar BMEP would be $625 (2009$) and $1,053 (2009$) for I-configuration and V-configuration engines, respectively. Similarly, for this proposal, the agencies are assuming the DMC of the 27 bar BMEP technology is 2.5x the DMC of the 18 bar BMEP technology, or $1,042 (2009$) and $1,756 (2009$) for I-configuration and V-configuration engines, respectively. For these 27 bar BMEP engine, the agencies assumed two stage turbos would be used to reach the boosting level. All of these turbocharger-related DMCs are considered applicable in MY 2012. 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 a long-term ICM of 1.29 to each thereafter. The resultant costs are shown in

Table V-36.

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[164] 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 No NHTSA-2010-0131.

Table V-36 Costs for Turbocharging (2009$)

Cost type	Technology (BMEP)	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	18 bar	I-engine	$361	$354	$347	$340	$333	$327	$320	$314	$308
DMC	18 bar	V-engine	$609	$597	$585	$573	$562	$551	$540	$529	$518
DMC	24 bar	I-engine	$542	$531	$521	$510	$500	$490	$480	$471	$461
DMC	24 bar	V-engine	$914	$896	$878	$860	$843	$826	$810	$793	$778
DMC	27 bar	I-engine	$904	$886	$868	$850	$833	$817	$800	$784	$769
DMC	27 bar	V-engine	$1,523	$1,493	$1,463	$1,434	$1,405	$1,377	$1,349	$1,322	$1,296
IC	18 bar	I-engine	$159	$159	$119	$118	$118	$118	$118	$117	$117
IC	18 bar	V-engine	$268	$267	$200	$199	$199	$199	$198	$198	$198
IC	24 bar	I-engine	$238	$238	$237	$237	$236	$236	$236	$235	$176
IC	24 bar	V-engine	$402	$401	$400	$399	$399	$398	$397	$396	$297
IC	27 bar	I-engine	$397	$396	$396	$395	$394	$393	$393	$392	$293
IC	27 bar	V-engine	$669	$668	$667	$665	$664	$663	$662	$661	$494
TC	18 bar	I-engine	$520	$513	$466	$459	$451	$445	$438	$431	$425
TC	18 bar	V-engine	$877	$864	$785	$773	$761	$749	$738	$727	$716
TC	24 bar	I-engine	$780	$769	$758	$747	$736	$726	$716	$706	$637
TC	24 bar	V-engine	$1,316	$1,296	$1,278	$1,259	$1,241	$1,224	$1,207	$1,190	$1,074
TC	27 bar	I-engine	$1,301	$1,282	$1,263	$1,245	$1,227	$1,210	$1,193	$1,176	$1,062
TC	27 bar	V-engine	$2,193	$2,161	$2,130	$2,099	$2,069	$2,040	$2,011	$1,983	$1,790

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

The cost for the downsizing portion of the turbo/downsize technology is more complex. The agencies have described those costs and how they were developed—based primarily on FEV teardowns but some were scaled to generate costs for downsizing situations that were not covered by teardowns—in both the 2012-2016 final rule and the TAR. The DMCs used for this analysis are identical to those used in the TAR, except that they have been updated to 2009 dollars. We note 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). However, the agencies' approach to calculating indirect costs 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 in the TAR. Given the history of the downsizing costs used by the agencies, many are considered applicable in MY 2012 and many in MY 2017.[165] All are considered to be on the flat portion of the learning curve.

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[165] The engine downsizing costs based on actual FEV teardowns were considered applicable to the 2012MY, as was explained for some downsizing costs in the 2012-2016 final rule and others in the TAR. For other downsizing 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 to result in cost estimates more appropriate for MY 2017. The new downsizing costs—those for V8 engines downsized to I4 engines—use a combination of V8 to V6 then V6 to I4 downsizing costs and are considered applicable to MY 2017 within the context of this analysis.

The agencies have applied a medium complexity ICM of 1.39 through 2018 and a long-term ICM of 1.29 thereafter. The resultant costs are shown in

Table V-37.

Table V-37 Costs for Engine Downsizing (2009$)

Cost type	Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	I4 DOHC to I3	-$171	-$168	-$164	-$161	-$158	-$155	-$152	-$149	-$146
DMC	I4 DOHC to I4	-$75	-$74	-$72	-$71	-$69	-$68	-$67	-$65	-$64
DMC	V6 DOHC to I4	-$485	-$475	-$466	-$457	-$447	-$438	-$430	-$421	-$413
DMC	V6 SOHC 2V to I4	-$339	-$332	-$325	-$319	-$313	-$306	-$300	-$294	-$288
DMC	V6 OHV to I4	$276	$268	$260	$252	$244	$237	$232	$227	$223
DMC	V8 DOHC to I4	-$839	-$814	-$789	-$766	-$743	-$720	-$706	-$692	-$678
DMC	V8 DOHC to V6	-$243	-$238	-$233	-$228	-$224	-$219	-$215	-$211	-$207
DMC	V8 SOHC 2V to I4	-$645	-$625	-$607	-$588	-$571	-$554	-$543	-$532	-$521
DMC	V8 SOHC 3V to I4	-$718	-$696	-$675	-$655	-$635	-$616	-$604	-$592	-$580
DMC	V8 SOHC 2V to V6	-$74	-$73	-$71	-$70	-$68	-$67	-$66	-$64	-$63
DMC	V8 SOHC 3V to V6	-$138	-$135	-$132	-$130	-$127	-$124	-$122	-$119	-$117
DMC	V8 OHV to I4	-$237	-$230	-$223	-$217	-$210	-$204	-$200	-$196	-$192
DMC	V8 OHV to V6	$322	$312	$303	$294	$285	$276	$271	$265	$260
IC	I4 DOHC to I3	$75	$75	$56	$56	$56	$56	$56	$56	$56
IC	I4 DOHC to I4	$33	$33	$25	$25	$25	$25	$25	$24	$24
IC	V6 DOHC to I4	$213	$213	$159	$159	$158	$158	$158	$158	$157
IC	V6 SOHC 2V to I4	$149	$149	$111	$111	$111	$111	$110	$110	$110
IC	V6 OHV to I4	$107	$106	$79	$79	$79	$79	$79	$78	$78
IC	V8 DOHC to I4	$325	$324	$241	$241	$240	$239	$239	$238	$238
IC	V8 DOHC to V6	$107	$106	$80	$79	$79	$79	$79	$79	$79
IC	V8 SOHC 2V to I4	$250	$249	$186	$185	$184	$184	$184	$183	$183
IC	V8 SOHC 3V to I4	$278	$277	$207	$206	$205	$205	$204	$204	$204
IC	V8 SOHC 2V to V6	$33	$33	$24	$24	$24	$24	$24	$24	$24
IC	V8 SOHC 3V to V6	$60	$60	$45	$45	$45	$45	$45	$45	$45
IC	V8 OHV to I4	$92	$92	$68	$68	$68	$68	$68	$67	$67
IC	V8 OHV to V6	$125	$124	$93	$92	$92	$92	$92	$91	$91
TC	I4 DOHC to I3	-$96	-$93	-$108	-$105	-$102	-$99	-$96	-$93	-$90
TC	I4 DOHC to I4	-$42	-$41	-$48	-$46	-$45	-$43	-$42	-$41	-$40
TC	V6 DOHC to I4	-$272	-$263	-$307	-$298	-$289	-$280	-$272	-$263	-$255
TC	V6 SOHC 2V to I4	-$190	-$183	-$214	-$208	-$202	-$196	-$190	-$184	-$178
TC	V6 OHV to I4	$383	$374	$339	$331	$323	$316	$311	$306	$301
TC	V8 DOHC to I4	-$514	-$490	-$548	-$525	-$503	-$481	-$467	-$453	-$440
TC	V8 DOHC to V6	-$136	-$131	-$154	-$149	-$145	-$140	-$136	-$132	-$128
TC	V8 SOHC 2V to I4	-$395	-$377	-$421	-$403	-$386	-$370	-$359	-$348	-$338
TC	V8 SOHC 3V to I4	-$440	-$419	-$469	-$449	-$430	-$412	-$400	-$388	-$376
TC	V8 SOHC 2V to V6	-$42	-$40	-$47	-$46	-$44	-$43	-$42	-$40	-$39
TC	V8 SOHC 3V to V6	-$77	-$75	-$87	-$84	-$82	-$80	-$77	-$75	-$72
TC	V8 OHV to I4	-$145	-$139	-$155	-$148	-$142	-$136	-$132	-$128	-$124
TC	V8 OHV to V6	$446	$436	$395	$386	$377	$368	$362	$357	$351

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 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 V-36 and

Table V-37, the costs for any turbo/downsize change considered by the agencies can be determined. These costs are shown in

Table V-38.

Table V-38 Total Costs for Turbo and Downsizing (2009$)

Downsize Technology	Turbo Technology (BMEP)	2017	2018	2019	2020	2021	2022	2023	2024	2025
I4 DOHC to I3	18 bar	$424	$420	$357	$353	$350	$346	$342	$338	$335
I4 DOHC to I3	24 bar	$685	$677	$650	$642	$635	$627	$620	$613	$547
I4 DOHC to I3	27 bar	$1,205	$1,189	$1,155	$1,140	$1,126	$1,111	$1,097	$1,083	$972
I4 DOHC to I4	18 bar	$478	$472	$418	$412	$407	$401	$396	$390	$385
I4 DOHC to I4	24 bar	$738	$728	$710	$701	$692	$683	$674	$665	$598
I4 DOHC to I4	27 bar	$1,259	$1,241	$1,216	$1,199	$1,183	$1,167	$1,151	$1,135	$1,022
V6 DOHC to I4	18 bar	$248	$250	$159	$161	$163	$164	$166	$168	$170
V6 DOHC to I4	24 bar	$509	$507	$451	$449	$448	$446	$444	$442	$382
V6 DOHC to I4	27 bar	$1,029	$1,019	$957	$948	$939	$930	$921	$913	$807
V6 SOHC 2V to I4	18 bar	$330	$329	$251	$250	$250	$249	$248	$247	$246
V6 SOHC 2V to I4	24 bar	$591	$586	$544	$539	$535	$530	$526	$522	$459
V6 SOHC 2V to I4	27 bar	$1,111	$1,098	$1,049	$1,037	$1,026	$1,014	$1,003	$992	$884
V6 OHV to I4	18 bar	$903	$887	$805	$789	$775	$760	$749	$737	$726
V6 OHV to I4	24 bar	$1,163	$1,143	$1,097	$1,078	$1,060	$1,042	$1,026	$1,012	$938
V6 OHV to I4	27 bar	$1,683	$1,656	$1,602	$1,576	$1,551	$1,526	$1,504	$1,482	$1,363
V8 DOHC to I4	18 bar	$6	$23	-$82	-$66	-$51	-$36	-$29	-$22	-$15
V8 DOHC to I4	24 bar	$266	$279	$210	$222	$234	$245	$249	$252	$197
V8 DOHC to I4	27 bar	$787	$792	$716	$720	$725	$729	$726	$723	$622
V8 DOHC to V6	18 bar	$741	$733	$631	$624	$616	$609	$602	$595	$588
V8 DOHC to V6	24 bar	$1,180	$1,165	$1,124	$1,110	$1,097	$1,084	$1,071	$1,058	$946
V8 DOHC to V6	27 bar	$2,057	$2,029	$1,976	$1,950	$1,925	$1,900	$1,875	$1,851	$1,662
V8 SOHC 2V to I4	18 bar	$125	$136	$45	$55	$65	$75	$79	$83	$87
V8 SOHC 2V to I4	24 bar	$385	$393	$337	$344	$350	$356	$357	$357	$299
V8 SOHC 2V to I4	27 bar	$906	$905	$842	$842	$841	$840	$834	$828	$724
V8 SOHC 3V to I4	18 bar	$81	$94	-$3	$9	$21	$33	$38	$43	$48
V8 SOHC 3V to I4	24 bar	$341	$350	$289	$298	$306	$314	$316	$318	$261
V8 SOHC 3V to I4	27 bar	$861	$863	$795	$796	$797	$799	$793	$788	$686
V8 SOHC 2V to V6	18 bar	$835	$824	$738	$727	$717	$707	$697	$687	$677
V8 SOHC 2V to V6	24 bar	$1,274	$1,256	$1,231	$1,214	$1,197	$1,181	$1,165	$1,149	$1,035
V8 SOHC 2V to V6	27 bar	$2,151	$2,121	$2,083	$2,053	$2,025	$1,997	$1,969	$1,943	$1,751
V8 SOHC 3V to V6	18 bar	$800	$790	$698	$688	$679	$670	$661	$652	$644
V8 SOHC 3V to V6	24 bar	$1,238	$1,222	$1,191	$1,175	$1,160	$1,144	$1,130	$1,115	$1,002
V8 SOHC 3V to V6	27 bar	$2,116	$2,086	$2,043	$2,015	$1,987	$1,960	$1,934	$1,908	$1,718
V8 OHV to I4	18 bar	$375	$374	$311	$310	$309	$309	$306	$303	$300
V8 OHV to I4	24 bar	$635	$631	$603	$599	$594	$590	$584	$578	$513
V8 OHV to I4	27 bar	$1,155	$1,143	$1,108	$1,097	$1,085	$1,074	$1,061	$1,048	$938
V8 OHV to V6	18 bar	$1,323	$1,301	$1,180	$1,159	$1,138	$1,118	$1,101	$1,084	$1,067
V8 OHV to V6	24 bar	$1,762	$1,733	$1,673	$1,646	$1,618	$1,592	$1,569	$1,547	$1,426
V8 OHV to V6	27 bar	$2,639	$2,597	$2,525	$2,485	$2,446	$2,408	$2,373	$2,340	$2,142

All costs are total costs (Direct manufacturing costs + Indirect costs); all costs are relative 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 proposed 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 above.

Cooled Exhaust Gas Recirculation/EGR Boost (CEGR)

Cooled exhaust gas recirculation (CEGR) or Boosted EGR is a combustion concept that involves utilizing EGR as a charge diluent 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.

In the TAR, the agencies considered this technology as an advanced gasoline engine technology because it was considered an emerging and not yet available technology in the light-duty gasoline vehicle market. 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.[166,167] While a cooled or "boosted" EGR technology was discussed in the MYs 2012-2016 rulemaking documents, the technology considered in this rulemaking is comparatively more advanced than the version described in the TAR. The agencies have therefore considered new costs and new effectiveness values for it. The effectiveness values used for engines with CEGR within this analysis were assumed by EPA and Ricardo to be 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 as described in TSD Section 3.3.1.2.

For this NPRM, the agencies have updated the effectiveness of engines with CEGR using the new Ricardo vehicle simulation modeling runs. For 24-bar BMEP engines with CEGR, designated in the CAFE model inputs as CEGR1, 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

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[166] Cairns *et al.*, Lotus, "Low Cost Solutions for Improved Fuel Economy in Gasoline Engines," Global Powertrain Congress September 27-29, 2005, vol. 33.

[167] 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. 7, 2011).

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 CEGR.[168,169] The agencies have also considered a more advanced version of CEGR for 27-bar BMEP engines, designated in the CAFE model inputs as CEGR2, that employs very high combustion pressures by using dual stage turbocharging, developed by Ricardo as part of the recent simulation modeling work supporting this rulemaking. The agencies have considered both of these CEGR approaches for this proposal.

Based on the data from the Ricardo and Lotus reports, NHTSA and EPA estimate the incremental reduction in fuel consumption for CEGR to be 5 percent over a turbocharged and downsized DI engine. Thus, if CEGR is applied to 24-bar engine, multiplicatively combining the 19.3 percent from the turbocharging and downsizing (TRBDS2) to the 5 percent gain from CEGR results in total fuel consumption reduction of 22.1 percent for CEGR1. 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 $242 (updated to 2009$) for this analysis. This DMC is considered applicable in MY 2012. The agencies consider CEGR technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2024 then a long-term ICM of 1.29 thereafter. The resultant costs are shown in Table V-39.

Table V-39 Costs for Cooled EGR (2009$)

Cost type	Engine type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	$210	$206	$202	$198	$194	$190	$186	$182	$179
IC	All	$92	$92	$92	$92	$92	$91	$91	$91	$68
TC	All	$303	$298	$294	$290	$285	$281	$277	$274	$247

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 CEGR 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 CEGR 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 in the engine design. As such, the CEGR system is considered applicable only to the 24 bar BMEP and 27 bar BMEP engines. Further, the agencies believe that 24 bar BMEP engines are capable of maintaining NO_x control without CEGR, so the models may choose 24 bar BMEP engines with and/or without CEGR, although 27 bar BMEP engines are considered to require CEGR to maintain NO_x emission control, so 27 bar BMEP technology cannot be applied in the analysis without also adding CEGR.

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[168] 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.

[169] Kapus, P.E., Fraidl, G.K., Prevedel, K., Fuerhapter, A. “GDI Turbo – The Next Steps,” JSAE Technical Paper No. 20075355, 2007.

Advanced Diesel Engine Technologies (ADSL)

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 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 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 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 NO_X emissions that have left the engine before they leave the vehicle tailpipe) are being introduced on Tier 2 compliant light-duty diesel vehicles today.

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. With the exception of EGR, 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 aftertreatment, the traditional 3-way catalyst aftertreatment used on gasoline-powered vehicles to meet criteria pollutant regulations is ineffective due to the lean-burn combustion of a diesel, because 3-way catalysts work only with stoichiometric engines. To reduce NOx, hydrocarbons, and particulate emissions, all diesels will require a diesel particulate filter (DPF) or catalyzed diesel particulate filter (CDPF), a diesel oxidation catalyst (DOC), and some kind of NO_x reduction strategy to comply with Tier 2 emissions standards. The most common NO_x reduction strategies include the use of lean NO_x traps (LNT)[170] or selective catalytic reduction (SCR).[171] A similar approach, but with greater catalyst volumes and potentially higher precious metal loading, would likely be used to meet potential and more stringent criteria emission standards. A fuel consumption penalty can be associated with some aftertreatment systems. This penalty is due to the fact that extra fuel is needed for the aftertreatment and this extra fuel is not used in the combustion process of the engine that provides torque to propel the vehicle thus reducing fuel efficiency.

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[170] A lean NO_x trap operates, in principle, by oxidizing NO to NO_2 in the exhaust and storing NO_2 on alkali sorbent material. When the control system determines (via mathematical model or a NO_x sensor) that the trap is saturated with NO_x, it switches the engine into a rich operating mode or may in some cases inject fuel directly into the exhaust stream to produce excess hydrocarbons that act as a reducing agent to convert the stored NO_x to N_2 and water, thereby "regenerating" the LNT and opening up more locations for NO_x to be stored. LNTs preferentially store sulfate compounds from the fuel, which can reduce catalytic performance. 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.

[171] 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 combines with NO_x in the SCR catalyst to form N_2 and water. The hardware configuration for an SCR system is 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.

Thus, both combustion improvements (for Tier 2 purposes) and aftertreatment may be associated with a fuel consumption and an emissions reduction penalty; this penalty combined with the extra cost of diesel emissions control technologies that are not necessary for gasoline engines 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:

First, we sought to ensure that diesel engines would have equivalent performance to comparable gasoline engine vehicles. The purpose of this approach is to provide an adequate assessment of diesel fuel consumption performance. 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 SCR systems and system efficiency. These assumptions impacted our estimates of the costs of implementing diesel engines as compared to the base gasoline engines. 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 MYs 2012-2016 final Joint TSD, Table 3-12 at page 3-44). See table V-8 of the document to convert the vehicle classes listed above and in the MYs 2012-2016 final Joint TSD to NHTSA subclasses. 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 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. 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.[172] The February 2011 values were used for purposes of this NPRM analysis because 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.[173] The forth 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 a long-term ICM of 1.29 thereafter. The resultant costs are shown in

Table V-40.

Table V-40 Costs for Conversion to Advanced Diesel (2009$)

Cost type	NHTSA Vehicle Subclass	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Subcompact PC, Subcompact Perf. PC, Compact PC, Midsize PC and Small LT	$2,039	$1,999	$1,959	$1,919	$1,881	$1,843	$1,807	$1,770	$1,735

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[172] 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.

[173] 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 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 proposed standards.

DMC	Compact Perf. PC, Midsize Perf. PC, Large PC, Minivan LT and Midsize LT	$2,061	$2,020	$1,980	$1,940	$1,901	$1,863	$1,826	$1,790	$1,754
DMC	Large Perf. PC and Large LT	$2,858	$2,800	$2,744	$2,690	$2,636	$2,583	$2,531	$2,481	$2,431
IC	Subcompact PC, Subcompact Perf. PC, Compact PC, Midsize PC and Small LT	$896	$895	$669	$668	$666	$665	$664	$663	$662
IC	Compact Perf. PC, Midsize Perf. PC, Large PC, Minivan LT and Midsize LT	$906	$904	$676	$675	$674	$672	$671	$670	$669
IC	Large Perf. PC and Large LT	$1,256	$1,253	$937	$935	$934	$932	$931	$929	$927
TC	Subcompact PC, Subcompact Perf. PC, Compact PC, Midsize PC and Small LT	$2,936	$2,893	$2,627	$2,587	$2,547	$2,509	$2,471	$2,433	$2,397
TC	Compact Perf. PC, Midsize Perf. PC, Large PC, Minivan LT and Midsize LT	$2,967	$2,924	$2,656	$2,615	$2,575	$2,535	$2,497	$2,460	$2,423
TC	Large Perf. PC and Large LT	$4,114	$4,053	$3,681	$3,625	$3,570	$3,515	$3,462	$3,410	$3,358

For the MYs 2012-016 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 based on the Ricardo 2011 study, and have now estimated the absolute effectiveness of a SCR-based diesel engine to be 28.4 to 30.5 percent.

Transmission Technologies

NHTSA and EPA reviewed the transmission technology estimates used in the MYs 2012-2016 final rule and the 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.

Improved Automatic Transmission Controls (IATC)

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. However, this operation can also 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 cannot be applied to DCTs..

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.

ASL 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.

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.[174] 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.

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[174] 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.

In the MYs 2012-2016 final rule, the agencies estimated an effectiveness improvement of 1 to 2 percent for aggressive shift logic and 0.5 percent for early torque converter lockup. This was supported by the 2002 NAS and NESCCAF reports as well as confidential manufacturer data. In this NPRM analysis, the agencies updated the effectiveness of ASL ranging from 1.9 to 2.7 based on the recent Ricardo study. For Early Torque Converter Lockup, the 2012-2016 final rule, TAR assumed an effectiveness improvement of 0.4 to 0.5 percent, and the recent Ricardo study confirmed that amount. In the CAFE model, NHTSA combines ASL and early torque converter (together named Improved Automatic Transmission Control (IATC)) and assigns it an incremental effectiveness ranging from 2.3 to 3.1 percent. This technology is applicable starting in MY 2012.

In the MYs 2012-2016 rule, the agencies estimated the DMC for ASL at $26 (2007$) and for early torque converter lockup at $23 (2007$), which was considered applicable to MY 2015. These DMCs become $27 for ASL and $24 for early torque converter lockup after being converted into 2009$. NHTSA added these costs together and applied it as IATC in the CAFE model. The agency considers IATC to be on the flat portion of the learning curve and applies a medium complexity ICM of 1.39 through 2018 then a long-term ICM of 1.29 thereafter. The resultant costs are shown in Table V-39.

Table V-41 Costs for IATC (2009$)

Index	Transmission Type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	$49	$48	$47	$46	$45	$44	$43	$42	$42
IC	All	$12	$12	$10	$10	$10	$10	$10	$10	$10
TC	All	$61	$60	$57	$56	$55	$54	$53	$52	$51

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

Automatic 6-speed Transmission (NAUTO)

Manufacturers can choose to replace 4- and 5-speed transmissions 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 gear ratios 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 is expected to be most prevalent for the timeframe of the 2012-2016 rulemaking, 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.[175] 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.[176] 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.

In this NPRM analysis, the agencies divided the improvement for this technology into two steps, first from 4- or 5- speed transmission to a 6-speed transmission (NAUTO), then from 6-speed transmission to 8 speed transmission (8SPD). The effectiveness estimates for NAUTO and 8SPD are based on the recent Ricardo study. In this section, only NAUTO is discussed. 8SPD will be discussed later in a section below.0

Based on the Ricardo study, 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). NHTSA incorporated this effectiveness estimate into the CAFE model as an incremental improvement over IATC ranging from 1.89 to 2.13 percent, because the Ricardo simulation-based estimates included improvements from IATC.

Based on the FEV teardown cost analysis, the DMC for 6-speed incremental to 5-speed automatic transmission is -$105.53 (2007$), that is, a cost savings. In MYs 2012-2016 final rule, the agencies also assumed an incremental cost of moving from a 4-speed transmission to a 5-speed transmission of $91 (2007$). Adding these two values, the agency derived the cost for a 6-speed automatic transmission, incremental to a 4-speed automatic transmission, as -$14 (2007$). Due to the fact that the market has significant amounts of both 4-speed and 5-speed automatic transmission already, NHTSA used the average of incremental cost from 4-speed to 6-speed and from 5-speed to 6-speed automatic transmission to represent the incremental cost of the NAUTO technology; that is, -$60 (2007$). Converting into 2009$, this DMC is -$62, which is applicable in MY 2012. 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 a long-term ICM of 1.19 thereafter. The resultant costs are shown in

Table V-42.

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[175] 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 http://www.zercustoms.com/news/More-Hybrids-from-GM-in-2008.html (last accessed on Nov 3, 2011)*

[176] "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 NHTSA-2010-0131

Table V-42 Costs for 6-Speed Automatic Transmissions (2009$)

Index	Transmission Type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	-$54	-$53	-$51	-$50	-$49	-$48	-$47	-$47	-$46
IC	All	$15	$15	$12	$12	$12	$12	$12	$12	$12
TC	All	-$39	-$38	-$40	-$39	-$38	-$37	-$36	-$35	-$34

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to 4/5-speed transmission.

Dual Clutch Transmission (DCT)

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.

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 considered in this analysis 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 the 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 the 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.
For purposes of this analysis, based on the 2011 Ricardo study, EPA and NHTSA have concluded that 8 to 13 percent effectiveness is appropriate for 6-speed DCTs compared to a baseline 4/5 speed transmission. 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, the effectiveness for the DCT, alone, is 4 to 5 percent (for wet-clutch designs) and 5 to 6 percent (for dry-clutch designs) compared to a baseline automatic transmission of similar vintage and number of fixed gears.

In this NPRM analysis, 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 with IATC based on the lumped parameter model. This effectiveness value also includes the accompanied 7 percent 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 LT, Midsize LT and Large LT.

Chapter 3 of the 2012-2016 final joint TSD referenced DCT costs of -$147 (2007$ and incremental to a 6-speed automatic transmission) based on an FEV tear-down study that assumed 450,000 units of production, but because the agencies did not consider there to be sufficient U.S. capacity in the 2012-2016 timeframe to produce 450,000 units, the tear-down values were adjusted accordingly. In contrast, the TAR timeframe for consideration was 2017-2025, so in that analysis the agencies assumed that production capacity would exist and that therefore the FEV tear-down results were valid without adjustment. We continue to believe that to be the case for purposes of this analysis. In the final joint TSD supporting the 2012-2016 rule the agencies 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, the agencies continue to consider this to be true.

For this analysis, then, the FEV teardown cost was employed for DCT. As stated in the MYs 2012-2016 final rule, the 6-speed wet DCT incremental to 6-speed automatic transmission is -$147 (2007$), and the incremental cost from a dry DCT to a wet DCT is $67 (2007$). The agency derived the 6-speed dry DCT cost incremental to 6-speed automatic transmission cost as -$147-$67 = -$214 (2007$). Converting to 2009$, the incremental cost from a 6-speed automatic transmission to 6-speed dry DCT is -$222 and the incremental cost from a 6-speed automatic transmission to 6-speed wet DCT is -$152. These costs are applicable in MY 2012. 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 a long-term ICM of 1.29 thereafter. The resultant costs are shown in

Table V-43.

Table V-43 Costs for 6-Speed Dual Clutch Transmissions (2009$)

Index	Transmission Type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Dry DCT	-$192	-$188	-$185	-$181	-$177	-$174	-$170	-$167	-$164
IC	Dry DCT	$84	$84	$63	$63	$63	$63	$63	$62	$62
TC	Dry DCT	-$108	-$104	-$122	-$118	-$114	-$111	-$108	-$104	-$101
DMC	Wet DCT	-$132	-$129	-$127	-$124	-$122	-$119	-$117	-$114	-$112
IC	Wet DCT	$58	$58	$43	$43	$43	$43	$43	$43	$43
TC	Wet DCT	-$74	-$71	-$83	-$81	-$79	-$76	-$74	-$72	-$69

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to 6-speed automatic transmission.

Automatic and Dual Clutch 8-Speed Transmission (8SPD)

As stated in the previous section under NAUTO, the agencies separated 8-speed transmission from NAUTO in consideration of the fact that an 8-speed transmission is more effective in reducing fuel consumption than 6-speed transmission, and more 8-speed automatic transmissions are beginning to enter the market.

In this NPRM analysis, the agencies assumed that 8-speed transmissions will not become available until MY 2017. NHTSA applied 8-speed automatic transmissions succeeding 6-speed automatic transmission to vehicles with towing requirements, such as minivans, midsize light trucks and large light trucks; all other vehicle subclasses use 8-speed DCT to succeed 6-speed DCT.

NHTSA derived effectiveness values from EPA's lumped parameter model, updated with values from the recent Ricardo study, for an 8-speed DCT relative to a 4-speed automatic transmission ranging from 11.1 to 13.1 percent for subclasses except Minivan LT, Midsize LT and Large LT, which assume an 8-speed automatic transmission relative to 4-speed automatic transmission ranging from 8.7 to 9.2 percent. This translates into effectiveness values appropriate for the CAFE model 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.

For the cost of an 8-speed automatic transmission, the agencies have relied on a tear-down study completed by FEV since publication of the TAR.[177] In that study, the 8 speed automatic transmission was found to have an incremental cost of $62 (2007$) compared to the 6 speed automatic transmission. Converting to 2009$, this DMC becomes $64 for this analysis. The agencies consider this DMC to be applicable to MY 2012, although, as stated, the technology will not be available for application until MY 2017. The agencies consider the 8 speed

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[177] FEV Inc., "Light-Duty Technology Cost Analysis: Advanced 8-speed Transmissions", Contract No. EP-C-07-069, Work Assignment 3-3, EPA-420-R-11-015, November 2011 Docket NHTSA-2010-0131

transmission technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through MY 2018 then a long-term ICM of 1.29 thereafter.[178] 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 rulemaking analysis. 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 estimation derived by NAS (see NAS 2010, Table 7-10).[179] For this proposal, we have chosen to use a DMC based on the more recent FEV tear-down analysis.

New for this analysis 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.[180] In that study, the 8 speed DCT was found to have an incremental cost of $198 (2007$) compared to the 6 speed DCT. Converting to 2009$, this DMC increment becomes $202 for this analysis. The agencies consider this DMC to be applicable to MY 2012. 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 MY 2024 then a long-term ICM of 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 8-speed automatic transmission and 8-speed DCTs incremental to 6-speed transmission with same transmission type are shown in

Table V-43.

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[178] This ICM would be applied to the 6 speed to 8 speed increment of $64 (2009$) applicable in 2012. The 4 speed to 6 speed increment would carry the low complexity ICM.

[179] National Academy of Sciences, “Assessment of Fuel Economy Technologies for Light-Duty Vehicles” Available at http://www.nap.edu/catalog.php?record_id=12924 (last accessed: November 15, 2011)

[180] FEV Inc., “Light-Duty Technology Cost Analysis: Advanced 8-speed Transmissions”, Contract No. EP-C-07-069, Work Assignment 3-3, EPA-420-R-11-015, November 2011 Docket NHTSA-2010-0131

Table V-44 Costs for 8-Speed Automatic and Dual Clutch Transmissions (2009$)

Index	Transmission Type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Auto	$55	$54	$53	$52	$51	$50	$49	$48	$47
IC	Auto	$24	$24	$18	$18	$18	$18	$18	$18	$18
TC	Auto	$80	$78	$71	$70	$69	$68	$67	$66	$65
DMC	DCT	$177	$174	$170	$167	$164	$160	$157	$154	$151
IC	DCT	$78	$78	$58	$58	$58	$58	$58	$58	$58
TC	DCT	$255	$251	$228	$225	$221	$218	$215	$212	$208

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to 6-speed transmission of same type.

High Efficiency Gear Box for Automatic, DCT and Manual Transmission (HETRANS and HETRANSM)

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.[181] 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 LPM effectiveness, resulting from these inputs, the agencies estimate that a high efficiency gearbox can provide a fuel consumption reduction in the range of 3.8 to 5.7 percent (3.8 percent for 4WD trucks with an unimproved rear axle) over a baseline transmission in MY 2017 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 V-27, is $193 (2009$). We have rounded this up to $200 for this analysis. This DMC is considered applicable for MY 2017. 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 a long-term ICM of 1.19 thereafter. The resultant costs are shown in

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[181] 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 NHTSA-2010-0131.

Table V-45.

Table V-45 Costs for High Efficiency Gearbox (2009$)

Index	Transmission Type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	$200	$194	$188	$183	$177	$172	$168	$165	$162
IC	All	$48	$48	$48	$48	$48	$48	$48	$48	$38
TC	All	$248	$242	$236	$231	$225	$220	$216	$213	$200

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to 8-speed transmission.

Shift Optimization (SHFTOPT)

In this NPRM analysis, the agencies introduced another level of aggressive shift logic based on the shift optimization algorithm employed in the recent Ricardo study. NHTSA named this technology Shift Optimization (SHFTOPT) in the CAFE model. As described in the 2011 Ricardo report, shift optimization is a 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. Thus, shift optimization tries to keep the engine operating near its most efficient point for a give power demand. The shift controller emulates a traditional CVT by selecting the best gear ratio for fuel economy at a given required vehicle power level to take full advantage of high BMEP engines.[182]

Ricardo acknowledged in its report that the shift optimization currently causes significant implications for drivability and hence affects consumer acceptability. However, Ricardo recommended the inclusion of this technology for the 2020-2025 time frame based on 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, more frequent 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 busyness 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 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 are developing means to mitigate these drivability issues by MY 2017, as assumed

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[182] In this analysis, the agencies have assumed that shift optimization may be applicable to all vehicles, but to the extent that high BMEP engines are an enabler for shift optimization, this assumption may require reconsideration for the final rule.

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. NHTSA seeks comment on the feasibility of the shift optimization strategy described above and the likelihood that and manner in which manufacturers will be able to overcome the drivability issues.

The effectiveness from the LPM for SHFTOPT ranges from 5.1 to 7.0 percent improvement over a transmission with non-optimized shift logic. In the CAFE model, an incremental effectiveness relative to IATC ranging from 3.27 to 4.31 percent is applied.

The agencies are estimating the DMC for SHFTOPT to be equivalent to ASL's cost of $27 (2009$) in relative to baseline transmission. Essentially this yield a nearly negligible incremental cost of $1 for SHFTOPT over IATC, which, combined with its effectiveness, makes it a very attractive technology for the model to apply in the analysis. This cost for SHFTOPT is considered applicable to MY 2017. The timing of SHFTOPT is different from that for ASL because SHFTOPT is newer and not yet being implemented in the fleet. The agencies consider SHFTOPT technology to be on the flat portion of the learning curve and have applied a medium complexity ICM of 1.39 through 2024 then a long-term ICM of 1.29 thereafter.

Table V-46 Cost for Shift Optimization (2009$)

Index	Transmission Type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	All	$1.0	$1.0	$0.9	$0.9	$0.9	$0.9	$0.8	$0.8	$0.8
IC	All	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2
TC	All	$1.2	$1.2	$1.2	$1.2	$1.1	$1.1	$1.1	$1.1	$1.0

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; cost incremental to IATC.

6-Speed Manual Transmissions (6MAN)

Manual transmissions depend entirely 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 MY 2012-2016 final rule assumed 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, NHTSA estimates 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 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 $232 (2009$) for this analysis, applicable in MY 2012. 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 a long-term ICM of 1.19 thereafter. NHTSA's resultant costs for a 6 speed manual transmission are shown in Table V-47.

Table V-47 Costs for 6 Speed Manual Transmission (2009$)

Index	Transmission Type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Manual	$221	$216	$212	$208	$204	$200	$196	$192	$188
IC	Manual	$56	$56	$45	$45	$45	$45	$45	$44	$44
TC	Manual	$277	$272	$257	$252	$248	$244	$240	$236	$232

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost; all costs are incremental to the baseline.

Vehicle Accessory, Hybridization and Electrification Technologies

Electrical Power Steering (EPS) and Electrohydraulic Power Steering (EHPS)

Electric power steering (EPS) and Electro-hydraulic power steering (EHPS) provide a potential reduction in 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.

In the 2012-2016 final rule, EPA and NHTSA estimated a 1 to 2 percent effectiveness for EPS based on the 2002 NAS report, Sierra Research Report and confidential OEM data. The 2010 Ricardo study also confirmed this estimate. The agencies continue to believe that these effectiveness estimates are accurate for the rulemaking timeframe, thus they have been retained for this proposal. For large pickup trucks the agencies used EHPS due to the utility requirement of these vehicles. The effectiveness of EHPS is estimated to be 0.8 percent based on the updated LPM results.

In the MY 2012-2016 final rule, the agencies estimated the DMC at $88 (2007$). Converting to 2009$, this DMC becomes $90 for this analysis, consistent with the recent heavy-duty GHG rule, and is considered applicable in MY 2015. 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, only 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 a long-term ICM of 1.19 thereafter. The resultant costs are shown in

Table 48.

Table 48 Costs of Electrical/Electro-hydraulic Power Steering (2009$)

Cost type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$86	$84	$82	$81	$79	$78	$76	$74	$73
IC	$22	$22	$17	$17	$17	$17	$17	$17	$17
TC	$108	$106	$100	$98	$96	$95	$93	$92	$90

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Improved Accessories Level 1 and Level 2(IACC1 and IACC2)

The accessories on an engine, including the alternator, coolant, and oil pumps, are traditionally mechanically-driven. A reduction in 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 also 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 an insignificant effect on efficiency. Therefore, the agencies decided to not include electric oil pump technology for this proposal.

In MYs 2012-2016 final rule, the agencies used an effectiveness value in the range of 1 to 2 percent based on the technologies discussed above. NHTSA did not apply this technology to large pickup trucks due to the utility requirement concern for this vehicle subclass.
For this proposal, the agencies are considering two levels of improved accessories. For level one of this technology (IACC1), NHTSA now incorporates a high efficiency alternator (70 percent efficient). 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 used in the 2012-2016 final rule and TAR for level IACC1. For this proposal, the agencies used an effectiveness value in 1.2 to 1.8 percent range varying based on different vehicle subclasses. For IACC1, NHTSA assumes an incremental effectiveness for this technology relative to EPS in the CAFE model of 0.91 to 1.61 percent, and an incremental effectiveness for IACC2 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 2009$, this DMC becomes $73 for this analysis, applicable in MY 2015, and consistent with the heavy-duty 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 a long-term ICM of 1.19 thereafter.

The assumed 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 $45 (2009$) incremental to IACC1, applicable in MY 2015. Including the costs for IACC1 results in a DMC for IACC2 of $118 (2009$) relative to the baseline case, and applicable in MY 2015. 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 a long-term ICM of 1.19 thereafter. The resultant costs are shown in Table V-49.

Table V-49 Costs for Improved Accessory Technology – Levels 1 & 2 (2009$)

Cost type	IACC Technology	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Level 1	$70	$68	$67	$66	$64	$63	$62	$61	$59
DMC	Level 2	$113	$110	$108	$106	$104	$102	$100	$98	$96
IC	Level 1	$18	$18	$14	$14	$14	$14	$14	$14	$14
IC	Level 2	$29	$29	$23	$23	$23	$23	$23	$23	$23
TC	Level 1	$87	$86	$81	$80	$78	$77	$76	$75	$73
TC	Level 2	$141	$139	$131	$129	$127	$124	$122	$120	$118

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost
Note that both levels of IACC technology are incremental to EPS in the CAFE model.

Air Conditioner Systems

Air conditioning (A/C) use places excess load on an engine, which results in additional fuel consumption and GHG emissions. A number of methods related only to the A/C system components and their controls can be used to improve A/C systems. The A/C improving technologies considered for this proposal 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 re-circulated cabin air). Technologies that reduce A/C related fuel consumption include internal heat exchanger, blower motor control, default to recirculated air, and reduced reheat with externally controlled with fixed or variable displacement compressor. Technologies that reduce air conditioning leakage or reduce the GWP of air conditioning refrigerant were not considered and are only included in the EPA GHG program. For purposes of this proposal, a detailed description of the A/C program can be found in Chapter 5 of the draft joint TSD. The reader is directed to that chapter to learn the specifics of the program, the fuel consumption improvement values involved, and details behind the costs that have been estimated.

Table V-50 is a copy of Table 5-17 from that chapter of the TSD, showing the total costs for A/C controls used in this proposal.

Table V-50 Costs of A/C Controls Carried Over into This Proposal (2009$)

Car/ Truck	Cost type	Rule	2017	2018	2019	2020	2021	2022	2023	2024	2025
Car	TC	Reference	$75	$74	$69	$68	$67	$66	$65	$64	$63
	TC	Control	$25	$40	$56	$65	$78	$76	$72	$70	$69
	TC	Both	$100	$114	$126	$133	$145	$142	$137	$134	$132
Truck	TC	Reference	$57	$56	$53	$52	$51	$50	$50	$49	$48
	TC	Control	$2	$46	$73	$81	$94	$92	$87	$85	$84
	TC	Both	$60	$102	$126	$133	$145	$142	$137	$134	$132
Fleet	TC	Both	$85	$110	$126	$133	$145	$142	$137	$134	$132

TC=Total cost

12 volt Micro Hybrid or Stop-Start (MHEV)

The stop-start technology we consider for this proposal—also known as idle-stop or 12-volt micro-hybrid—is the most basic hybrid system that facilitates idle-stop capability. When the vehicle comes to a stop, the system will automatically shut down the internal combustion engine and restart the engine when vehicle starts to move again. This is especially beneficial to reduce fuel consumption when vehicles spend significant amount of time stopped in traffic. 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, for this analysis this technology is applied to all vehicle classes, including large pickup trucks.

In the MYs 2012-2016 final rule, the effectiveness NHTSA used in the CAFE model ranged from 2 to 4 percent, depending on whether the vehicle was 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 NPRM analysis, 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. For CAFE modeling, the incremental effectiveness for 12V stop-start relative to IACC2 is 1.68 to 2.2 percent.

In the MYs 2012-2016 final rule, the agencies estimated the DMC at $282 (2007$) to $350 (2007$) for small cars through large trucks, respectively. Converting to 2009$, these DMCs become $290 (2009$) through $361 (2009$) for this analysis, and are considered applicable in MY 2015. 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 a long-term ICM of 1.29 thereafter. The resultant costs are shown in

Table V-51.

Table V-51 Costs for 12V Micro Hybrid (2009$)

Cost type	NHTSA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Subcompact PC/Perf PC	$230	$223	$217	$210	$204	$198	$192	$186	$180
DMC	Compact PC/Perf PC	$249	$242	$234	$227	$220	$214	$207	$201	$195
DMC	Midsize PC/Perf PC	$273	$265	$257	$250	$242	$235	$228	$221	$214
DMC	Large PC/Perf PC	$294	$285	$276	$268	$260	$252	$245	$237	$230
DMC	Minivan	$294	$285	$276	$268	$260	$252	$245	$237	$230
DMC	Midsize LT	$301	$292	$283	$275	$266	$258	$251	$243	$236
DMC	Small LT	$260	$252	$244	$237	$230	$223	$216	$210	$204
DMC	Large LT	$340	$330	$320	$310	$301	$292	$283	$275	$267
IC	Subcompact PC/Perf PC	$92	$91	$68	$68	$68	$68	$67	$67	$67
IC	Compact PC/Perf PC	$99	$99	$74	$73	$73	$73	$73	$73	$72
IC	Midsize PC/Perf PC	$109	$108	$81	$81	$80	$80	$80	$80	$80
IC	Large PC/Perf PC	$117	$116	$87	$87	$86	$86	$86	$86	$85
IC	Minivan	$117	$116	$87	$87	$86	$86	$86	$86	$85
IC	Midsize LT	$120	$119	$89	$89	$88	$88	$88	$88	$88
IC	Small LT	$103	$103	$77	$77	$76	$76	$76	$76	$76
IC	Large LT	$135	$135	$101	$100	$100	$100	$100	$99	$99
TC	Subcompact PC/Perf PC	$322	$315	$285	$278	$272	$265	$259	$253	$247
TC	Compact PC/Perf PC	$348	$340	$308	$301	$294	$287	$280	$274	$268
TC	Midsize PC/Perf PC	$382	$374	$338	$330	$322	$315	$308	$301	$294
TC	Large PC/Perf PC	$411	$401	$363	$355	$346	$338	$331	$323	$316
TC	Minivan	$411	$401	$363	$355	$346	$338	$331	$323	$316
TC	Midsize LT	$421	$411	$372	$363	$355	$347	$339	$331	$323
TC	Small LT	$363	$355	$321	$314	$306	$299	$292	$286	$279
TC	Large LT	$476	$465	$421	$411	$401	$392	$383	$374	$366

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

High Voltage Stop-Start/Belt Integrated Starter Generator (ISG)

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 electric power steering and an auxiliary automatic transmission pump. The limited electrical requirements of these systems allow the use of lead-acid batteries or super-capacitors for energy storage. This technology exists in the baseline fleet, but is not used as an enabling technology for this NPRM analysis.

Integrated Motor Assist (IMA)/Crank Integrated Starter Generator

IMA is a system developed and marketed by Honda[183] 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/CISG systems capable of all-electric drive are under development. IMA and CISG could be applied to all classes of vehicles. 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 2008 baseline fleet. Neither NHTSA nor EPA used this technology as an enabling technology in this NPRM analysis.

Batteries for HEV, PHEV and EV Applications

The design of battery secondary cells can vary considerably between MHEV, 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 ultra-batteries)

MHEV systems using electrolytic double-layer capacitors are also under development and may provide improved performance and reduced cost in the post-2017 timeframe.

HEV batteries: HEV applications operate in a narrow, short-cycling, charge-sustaining state of charge (SOC). Energy capacity in 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. 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 V-16).

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[183] http://automobiles.honda.com/insight-hybrid/features.aspx?Feature=ima (last accessed on November 14, 2011)

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 reduced the specific cost on a per-kW-hr 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 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.[184] 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 for charge sustaining operation.[185]

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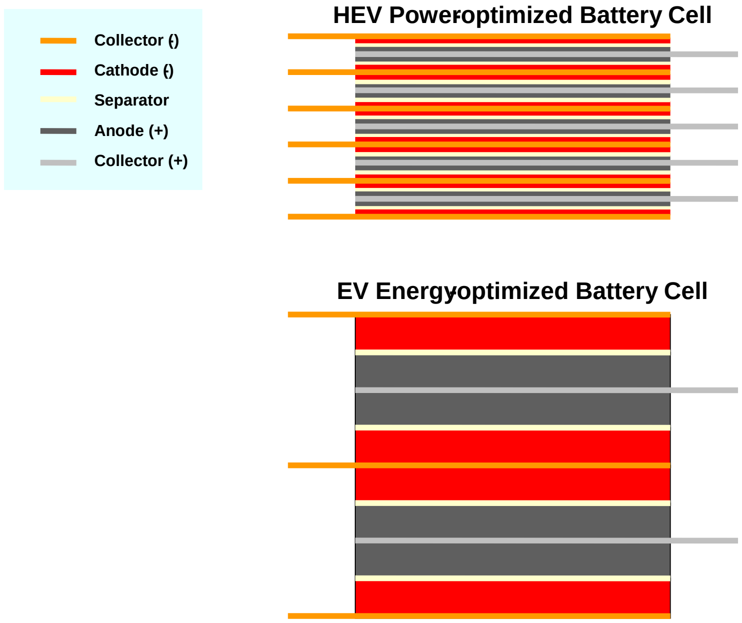
[184] "Latest Chevrolet Volt Battery Pack and Generator Details and Clarifications." Lyle Dennis interview of Rob Peterson (GM) regarding the all-electric drive range of the GM Volt, August 29, 2007. Accessed on the Internet on November 14, 2011 at http://gm-volt.com/2007/08/29/latest-chevy-volt-battery-pack-and-generator-details-and-clarifications/

[185] "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 No. NHTSA-2010-0131 or available at http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2009/vehicles_and_systems_simulation/vss_15_bohn.pdf (last accessed November 14, 2011)

Figure V-16: Schematic representation of power and energy optimized prismatic-layered battery cells



Power-split hybrid vehicles from Toyota, Ford and Nissan (which uses the Toyota system under license), 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 electrical-energy-intensive automotive 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 i-Miev 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 – $LiMn_2O_4$-spinel (CPI, GS-Yuasa, AESC) and $LiFePO_4$ (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 large-format 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.

HEV, PHEV and EV System Sizing and Cost Estimating 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 is 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 and how battery costs are derived by EPA using ANL's BatPac model.

Battery Pack Sizing and Hybrid System Sizing

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.

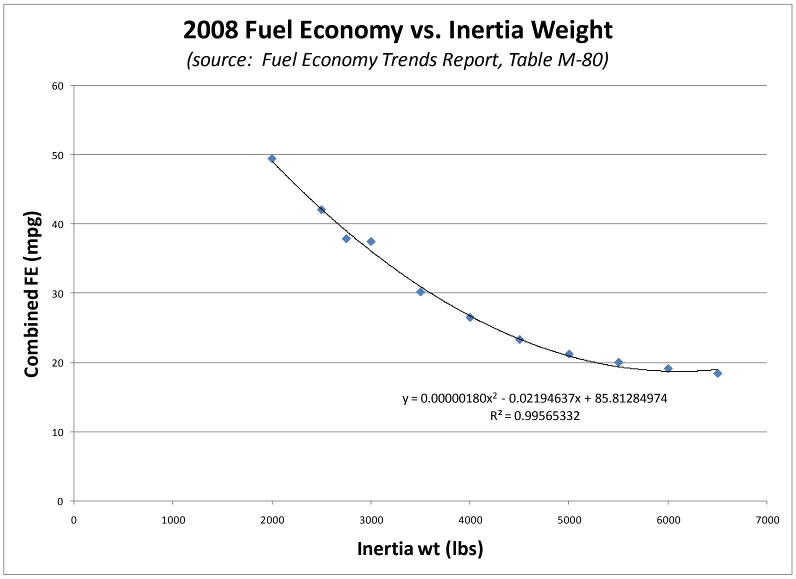
EPA built spreadsheets to estimate the required battery size for each vehicle and class. Listed below are the steps EPA has taken in these spreadsheets to estimate not only battery size, but associated weight for EVs and PHEVs of varying ranges and designs.

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?

Iterate steps 2-6 until assumed weight reduction target (and nominal vehicle weight) reconciles with required battery size and calculated weight of vehicle.

Baseline vehicle energy consumption is estimated based on a fitted trendline for fuel economy versus inertia weight, or estimated test weight (ETW) (from FE Trends data for 2008 MY vehicles, table M-80) and converting to Wh/mi. It is shown in Figure V-17.

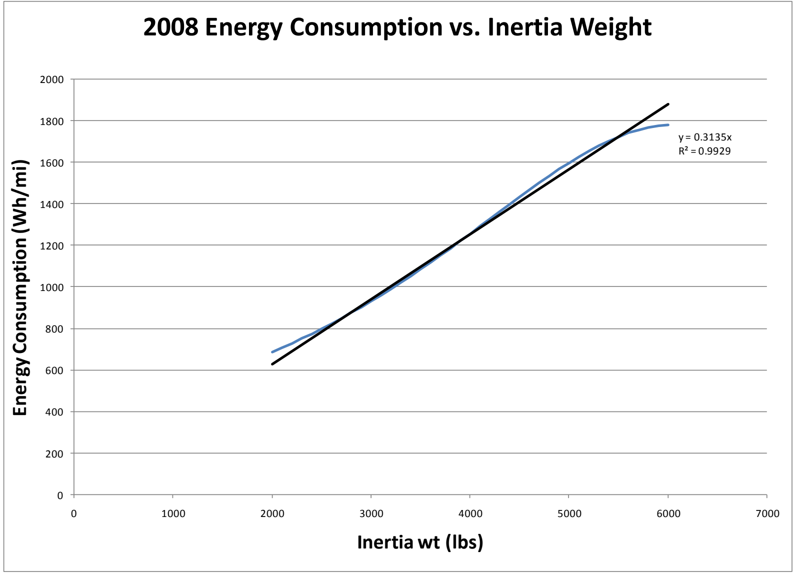
Figure V-17
Average fuel economy based on inertia weight (ETW) from FE Trends data



Then, fuel economy was converted into energy consumption (assuming 33,700 Wh energy in 1 gallon of gasoline) and used to populate a range of test weights between 2,000 and 6,000 lbs. A linear trend line was used to fit this curve and then applied for estimating generic energy consumption for baseline vehicles of a given ETW, and is shown below in

Figure V-18.

Figure V-18
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 V-52 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 resistanceVehicle 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 V-52: EV efficiency and energy demand calculations

Overall EV efficiency calculations, by vehicle class

Class	Brake eff	D/L eff	Wheel eff	Cycle eff	Vehicle efficiency	Road Loads	Energy Reduction	**Energy** Efficiency Increase	IW-based base ICE nominal mpgge	Base fuel energy reqd W-hr/mi	FTP fuel energy reqd W-hr/mi	Onroad fuel energy reqd W-hr/mi
Baseline gas ICE	24%	81%	20%	77%	15%	100%						
Subcompact	85%	93%	79%	97%	77%	91%	**82%**	464%	37	911	**161**	**230**
Small car	85%	93%	79%	97%	77%	91%	**82%**	464%	32	1060	**188**	**268**
Large car	85%	93%	79%	97%	77%	91%	**82%**	464%	26	1279	**227**	**324**
Small Truck	85%	93%	79%	97%	77%	91%	**82%**	464%	26	1314	**233**	**333**
Minivan	85%	93%	79%	97%	77%	91%	**82%**	464%	24	1401	**248**	**355**
Truck	85%	93%	79%	97%	77%	91%	**82%**	464%	21	1597	**283**	**404**

The energy efficiency of a baseline vehicle (around 15 percent), 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 95% 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 10% weight reduction, road loads (as calculated by the LP model) are reduced to 91% of the baseline vehicle.[186]

  The energy consumption of the EV includes ratio of the road loads 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 V-1.

Equation V-1: EV energy consumption

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[186] Included in this example road load calculation is a 10% reduction in rolling resistance and aerodynamic drag.

In the
Table V-52, 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 W-hr/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 from 2006 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 V-2:

Equation V-2: Required battery pack energy (size) for EVs

Assumed usable SOC windows were 80% for EVs (10-90%) and 70% for PHEVs (15%-85%). The battery pack sizes are listed in orange in Table V-53 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 V-53: Battery pack sizes for 100-mile EV based on inertia weight

Category	BASELINE curb wt lbs	Inertia wt lbs	EV unadj Wh/mi	EV adj Wh/mi	100 mi batt pack size kWh
Subcompact	2628	2928	161	230	28.8
Small car	3118	3418	188	268	33.5
Large car	3751	4051	227	324	40.5
Small Truck	3849	4149	233	333	41.6
Minivan	4087	4387	248	355	44.3
Truck	4646	4946	283	404	50.5

EPA used Equation V-3 to determine weight of an EV:

Equation V-3: EV weight calculation

Any weight reduction technology was applied only to the glider (baseline vehicle absent powertrain) as defined in Equation V-4:

Equation V-4: Weight reduction of the glider

In the case of PHEVs, it was assumed that the base ICE powertrain remains so it is not deducted; the proper equation for PHEVs is shown in equation V-5**:**

Equation V-5: Weight calculation for PHEV

Listed in Table V-54 are the assumed baseline ICE-powertrain weights, by vehicle class:

Table V-54: Baseline ICE-powertrain weight assumptions, by class

ICE powertrain weight estimates							
Class	Engine	Trans (diff not included)	Fuel system (50% fill)	Engine mounts/NVH treatments	Exhaust	12V battery	Total ICE powertrain weight
Subcompact	250	125	50	25	20	25	**495**
Small car	300	150	60	25	25	30	**590**
Large car	375	175	70	25	30	35	**710**
Small Truck	300	150	60	25	25	30	**590**
Minivan	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.[187] 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 $W_{electric\_drive}$.[188] A summary table of electric drive weights for 100-mile EVs is shown in Table V-53:

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[187] 150 Wh/kg is a conservative estimate for year 2017 and beyond: outputs from ANL’s battery cost model show specific energy values of 160- 180 Wh/kg for a similar timeframe.

[188] 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 V-55: Total electric drive weights for 100-mile EVs

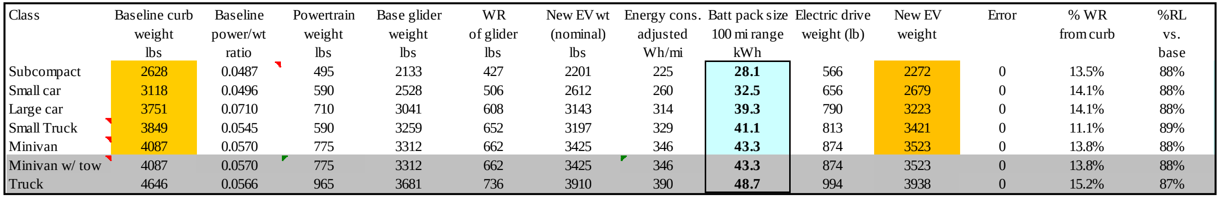
EV powertrain weight estimates - 100 mile range

Class	Battery pack size (kWh)	2020 electric content (lbs)	Gearbox (power-split or other)	2020 EV powertrain total
Subcompact	28.8	528	50	**578**
Small car	33.5	615	60	**675**
Large car	40.5	742	70	**812**
Small Truck	41.6	762	60	**822**
Minivan	44.3	813	80	**893**
Truck	50.5	926	100	**1026**

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 V-56 shows example results for 100-mile range EVs; in this case a 10% applied glider weight reduction for a variety of vehicle classes.

Table V-56: Sample calculation sheet for 100-mile EVs



Class	Baseline curb weight lbs	Baseline power/wt ratio	Powertrain weight lbs	Base glider weight lbs	WR of glider lbs	New EV wt (nominal) lbs	Energy cons. adjusted Wh/mi	Batt pack size 100 mi range kWh	Electric drive weight (lb)	New EV weight	Error	% WR from curb	%RL vs. base
Subcompact	2628	0.0487	495	2133	427	2201	225	**28.1**	566	2272	0	13.5%	88%
Small car	3118	0.0496	590	2528	506	2612	260	**32.5**	656	2679	0	14.1%	88%
Large car	3751	0.0710	710	3041	608	3143	314	**39.3**	790	3223	0	14.1%	88%
Small Truck	3849	0.0545	590	3259	652	3197	329	**41.1**	813	3421	0	11.1%	89%
Minivan	4087	0.0570	775	3312	662	3425	346	**43.3**	874	3523	0	13.8%	88%
Minivan w/ tow	4087	0.0570	775	3312	662	3425	346	**43.3**	874	3523	0	13.8%	88%
Truck	4646	0.0566	965	3681	736	3910	390	**48.7**	994	3938	0	15.2%	87%

Table V-57 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 V-57: 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
Subcompact	19%	14%	2%	12%	7%
Small car	19%	14%	2%	12%	7%
Large car	19%	14%	2%	12%	7%
Small Truck	16%	11%	-1%	12%	8%
Minivan	19%	14%	2%	12%	7%
Truck (w/ towing)	19%	14%	2%	10%	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.

HEV, PHEV and EV Battery Pack 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.[189] 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 as PHEVs.[190] In

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[189] 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 Docket No. NHTSA-2010-0131 or Available at http://www.transportation.anl.gov/pdfs/B/624.PDF (last accessed November 14, 2011)

[190] 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. Available at http://www.docin.com/p-99138808.html (last accessed November 14, 2011)

early 2011, ANL issued a draft report detailing the methodology, inputs and outputs of their Battery Performance and Cost (BatPac) model.[191] A complete independent peer-review of the BatPac model and its inputs and results for HEV, PHEV and EV applications has been completed.[192] ANL recently provided the agencies with an updated report documenting the BatPac model that addresses many of the issues raised within the peer review.[193] Based on the feedback from peer-reviewers, ANL has updated the model in the following areas:

1. Battery pack price 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 states in the report that the closure design it uses in the model does not have sufficient surface area to be cooled by air effectively as shown in Table 5.3 in the report.

This model and the peer review report will be made public with this NPRM and put into docket NHTSA-2010-0131.

NHTSA and EPA have decided to use the updated ANL BatPac model, dated July 17, 2011, for estimating large-format lithium-ion batteries for this 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-

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[191] The ANL draft report can be found at Docket No. NHTSA-2010-0131

[192] The ANL peer review can be found in at Docket No. NHTSA-2010-0131

[193] The ANL final report on BatPac can be found at Docket No. NHTSA-2010-0131

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 the type of thermal management employed (BatPaC is limited to liquid cooling and does not support passive or active air cooling), or the packaging of cells and modules in a pack (parallel modules are not supported), changes can often be made by modifying the relevant cost outputs or performing workarounds in the use of the model.

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 seven classes of vehicles (Subcompact, Small Car, Large Car, Small Truck, Minivan, Minivan with Towing, Large 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 each, 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 NPRM analysis.

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 80 A-hr.

EPA made several modeling assumptions that differed from the default model: (1) The SOC window for PHEV20 was limited to 50% rather than the default 70%. (2) The SOC window for HEVs was increased to 40% rather than the default 25%. (3) EV packs were modeled as two half-packs to avoid exceeding pack voltage guidelines. Although the model provided for a potential solution by placing parallel cells within modules, EPA felt that likely industry practices would be better represented by placing parallel modules within a pack, or by dividing the pack into two parallel packs for packaging flexibility. Because the model did not support parallel modules, each EV pack was modeled as two half-packs, each at half the target power and energy, to be installed in parallel. Per ANL recommendation, half-packs were modeled at twice the full-pack production volume, the projected half-pack cost was then doubled, and costs for the battery management system (BMS), disconnects, and thermal management were added only once, and module controls added twice. (4) HEV packs were assumed to be air cooled instead of liquid cooled (except for large work trucks and minivans with towing, which are still modeled as liquid-cooled). Because the model did not support air cooling, EPA replaced the model's projected cost for liquid cooling with a cost for air cooling (blower motor, ducting, and temperature feedback) derived from FEV's teardown studies. EPA is working with ANL and investigating the potential for modifying the BatPac model to include air cooling as an option Additionally, EPA did not include warranty costs computed by BatPaC in the total battery cost because these are accounted for elsewhere in the agencies' rulemaking analysis by means of indirect cost multipliers (ICMs).

Table V-58 Summary of Inputs and Assumptions Used with BatPaC

Category of input/Assumptions	**BatPaC Default or Suggested Values**	**Agency Inputs for NPRM Analysis**
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%

SOC window for PHEV20	70%	50%
Thermal management	Liquid	Air, for small/medium HEVs Liquid for all others
EV pack configuration	• Single pack, cells in series • Single pack, some parallel cells	Two packs, cells in series, packs in parallel

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 $167/kWh for EV150 large truck to $267/kWh for PHEV40 large car with NMC as chemistry and to $375/kWh for PHEV20 sub-compact car as shown in Table V-59. The agencies recognize 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. The agencies also reviewed publically available PHEV and EV battery cost literature including reports from Anderman,[194] Frost & Sullivan,[195] TIAX,[196] Boston Consulting Group,[197] NRC,[198] etc. EPA and NHTSA anticipate that public comment or further research may lead to the use of different inputs and assumptions that may change the cost projections used for the final rule.

Due to the uncertainties inherent in estimating battery costs through the 2025 model year, a sensitivity analysis is provided in Chapter X below using a a range of costs estimated by DOE technical experts to represent what they consider to be 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 have used this suggested range for the sensitivity study.

Figure V-19. Table from ANL Recommendation[199]

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[194] 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

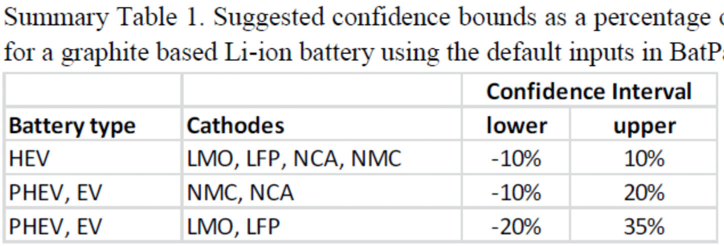
[195] Frost & Sullivan (2009b) World Hybrid Electric and Electric Vehicle Lithium-ion Battery Market, N6BF-27, Sep 2009

[196] Barnett, B. et al (2009) PHEV battery cost assessment (slides), TIAX LLC, es_02_barnett, May 19, 2009

[197] Boston Consulting Group (2010) Batteries for Electric Cars – Challenges, Opportunities, and the Outlook to 2020

[198] National Research Council (2010) Transitions to Alternative Transportation Technologies--Plug-in Hybrid Electric Vehicles.

[199] K. G. Gallagher, P. A. Nelson, (2010) "An Initial BatPac Variation Study" in Docket: NHTSA-2010-0131.



Summary Table 1. Suggested confidence bounds as a 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%

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.[200,201,202,203] The specific cost outputs from the BatPaC model used by NHTSA in this analysis pre-consideration of mass reduction are shown in Table V-59.

Table V-59 MY2017 Direct Manufacturing Costs (2009$) for P2 HEV, PHEVs and EVs at 0% Net Vehicle Mass Reduction

NHTSA Vehicle Class	**P2 HEV (LMO) @ 450K/yr volume**		**PHEV20 (LMO) @ 450K/yr volume**		**PHEV40 (NMC) @ 450K/yr volume**		**EV75 (NMC) @ 450K/yr volume**		**EV100 (NMC) @ 450K/yr volume**		**EV150 (NMC) @ 450K/yr volume**	
	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh	Pack	$/kWh
Subcompact PC/Perf. PC Compact PC/Perf. PC	$716	$886	$2,602	$375	$3,655	$264	$5,418	$238	$6,360	$210	$8,292	$182
Midsize PC/Perf. PC	$757	$802	$2,746	$340	$4,043	$251	$5,892	$223	$7,001	$198	$9,189	$174
Large PC/Perf. PC	$864	$772	$3,331	$342	$5,193	$267	$7,180	$225	$8,101	$190	$10,991	$172
Minivan/Midsize LT	$928	$766	$3,296	$309	$5,041	$236	$7,198	$206	$8,414	$180	$11,747	$168
Small LT	$822	$717	$3,143	$314	$4,788	$239	$6,827	$208	$8,047	$184	$11,253	$170
Large LT	$964	$706	$3,522	$290	$5,512	$227	$7,613	$191	$9,232	$174	$13,337	$167

Due to the weight increases of adding electrification system such as battery pack, and the weight decreases by applying smaller or no conventional internal combustion system for HEVs,

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[200] "Hyundai ups tech ante with Sonata Hybrid," Automotive News, August 2, 2010. Available at http://www.autonews.com/apps/pbcs.dll/article?AID=/20100802/RETAIL03/308029942/1186 (last accessed November 14, 2011)

[201] "Chevrolet Stands Behind Volt With Standard Eight-Year, 100,000-Mile Battery Warranty," GM Press release available at http://media.gm.com/content/media/us/en/news/news_detail.brand_gm.html/content/Pages/news/us/en/2010/July/0714_volt_battery (last accessed: November 14, 2011)

[202] "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. Available at http://ev.sae.org/article/7651 (last accessed November 14, 2011)

[203] "Lithium-ion Battery," Nissan Global Technology Information Available at http://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/li_ion_ev.html (last accessed November 14, 2011)

PHEVs and EVs, the net mass reduction for HEV, PHEV and EV varies for different electrification packages and vehicle classes. The agencies estimated vehicle mass reduction offsets for different electrification packages as shown in

Table V-60. These mass reduction offsets can be positive or negative depending on whether the added electrification system is heavier or lighter than the mass change due to the downsized conventional powertrain or even the elimination of the conventional internal combustion system. For example, for a 20-mile range subcompact PHEV shown in

Table V-60, a 5% mass reduction of the glider (vehicle systems not including powertrain) is offset by the additional weight of the electrification system, and therefore 5% mass reduction is needed to achieve a net 0% overall vehicle mass reduction. On the other hand, for a 75-mile range midsize electric passenger car, because conventional engine and transmission weigh more than the addition of electrification systems, a net mass reduction of 1 percent can be achieved by simply switching from conventional gasoline powered vehicle to EV75 without applying any mass reduction to the glider. The agencies differentiate between "applied" mass reduction and "net" mass reduction in this analysis. The applied mass reduction is the mass reduction applied to a vehicle to achieve the net mass reduction after considering the interaction between mass reduction and electrification system, *i.e.*, the applied mass reduction includes all the offsets shown in

Table V-60.

Table V-60 Mass reduction Offset Associated with Electrification Technologies

Vehicle Class	P2 HEV	PHEV20	PHEV40	EV75	EV100	EV150
Subcompact	5%	7%	13%	0%	6%	18%
Small car	5%	7%	12%	-1%	5%	17%
Large car	5%	7%	13%	-1%	5%	18%
Minivan	5%	7%	13%	-1%	6%	18%
Small truck	5%	7%	12%	3%	8%	20%
Minivan with towing	6%	8%	14%	-1%	6%	18%
Large truck	6%	9%	14%	-2%	4%	16%

Using the ANL model outputs, the agencies calculated battery system costs for HEVs, PHEVs and EVs for different vehicle classes with different level of mass reduction. These results are summarized in

Table V-61 to Table V-66. NHTSA assumes that all minivan and midsize light truck will maintain current towing capability so that consumers will not lose that functionality moving to electrified vehicles.

Table V-61 MY2017 Direct Manufacturing Costs for P2 HEV packages at different levels of applied vehicle mass reduction (2009 dollars, markups not included)

P2 HEV (LMO) @ 450K/yr volume		**0% mass reduction**		**2% mass reduction**		**7.5% mass reduction**		**10% mass reduction**		**20% mass reduction**	
EPA Vehicle Class	**NHTSA Vehicle Class**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**
Subcompact	Subcompact PC/Perf. PC Compact PC/Perf. PC	$716	$886	$713	$898	$704	$934	$700	$951	$691	$997
Small Car	Midsize PC/Perf. PC	$757	$802	$754	$813	$743	$845	$739	$861	$725	$900
Large Car	Large PC/Perf. PC	$864	$772	$858	$781	$843	$809	$836	$823	$819	$859
Minivan		$847	$699	$842	$708	$828	$734	$821	$747	$803	$779
Minivan +towing	Minivan Midsize LT	$928	$766	$923	$776	$909	$806	$902	$821	$887	$851
Small Truck	Small LT	$822	$717	$817	$727	$802	$752	$796	$765	$781	$801
Large Truck	Large LT	$964	$706	$958	$715	$942	$742	$934	$755	$920	$783

Table V-62 MY2025 Direct Manufacturing Costs for PHEV20 packages at different levels of applied vehicle mass reduction (2009 dollars, markups not included)

PHEV20 (LMO) @ 450K/yr volume		**0% mass reduction**		**2% mass reduction**		**7.5% mass reduction**		**10% mass reduction**		**20% mass reduction**	
EPA Vehicle Class	**NHTSA Vehicle Class**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**
Subcompact	Subcompact PC/Perf. PC Compact PC/Perf. PC	$2,602	$375	$2,585	$377	$2,539	$381	$2,516	$382	$2,501	$384
Small Car	Midsize PC/Perf. PC	$2,746	$340	$2,726	$342	$2,671	$345	$2,647	$345	$2,628	$347
Large Car	Large PC/Perf. PC	$3,331	$342	$3,299	$343	$3,213	$343	$3,176	$343	$3,145	$344
Minivan		$3,296	$309	$3,267	$310	$3,188	$311	$3,153	$311	$3,126	$312
Minivan +towing	Minivan Midsize LT	$3,296	$309	$3,267	$310	$3,188	$311	$3,153	$311	$3,139	$313
Small Truck	Small LT	$3,143	$314	$3,116	$315	$3,042	$316	$3,010	$317	$2,974	$319
Large Truck	Large LT	$3,522	$290	$3,470	$289	$3,381	$289	$3,342	$289	$3,334	$290

Table V-63 MY2025 Direct Manufacturing Costs for PHEV40 packages at different levels of applied vehicle mass reduction (2009 dollars, markups not included)

PHEV40 (NMC) @ 450K/yr volume		**0% mass reduction**		**2% mass reduction**		**7.5% mass reduction**		**10% mass reduction**		**20% mass reduction**	
EPA Vehicle Class	**NHTSA Vehicle Class**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**
Subcompact	Subcompact PC/Perf. PC Compact PC/Perf. PC	$3,655	$264	$3,622	$264	$3,590	$268	$3,590	$268	$3,590	$268
Small Car	Midsize PC/Perf. PC	$4,043	$251	$3,986	$250	$3,883	$250	$3,888	$251	$3,888	$251
Large Car	Large PC/Perf. PC	$5,193	$267	$5,128	$266	$4,969	$266	$4,969	$266	$4,969	$266
Minivan		$5,041	$236	$4,985	$236	$4,883	$238	$4,893	$237	$4,893	$237
Minivan +towing	Minivan Midsize LT	$5,041	$236	$4,985	$236	$4,905	$239	$4,916	$238	$4,916	$238
Small Truck	Small LT	$4,788	$239	$4,737	$239	$4,602	$239	$4,598	$239	$4,598	$239
Large Truck	Large LT	$5,512	$227	$5,449	$227	$5,345	$226	$5,345	$226	$5,345	$226

Table V-64 MY2025 Direct Manufacturing Costs for EV75 packages at different levels of applied vehicle mass reduction (2009 dollars, markups not included)

EV75 (NMC) @ 450K/yr volume		0% mass reduction		2% mass reduction		7.5% mass reduction		10% mass reduction		20% mass reduction	
EPA Vehicle Class	**NHTSA Vehicle Class**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**
Subcompact	Subcompact PC/Perf. PC Compact PC/Perf. PC	$5,418	$238	$5,384	$239	$5,340	$244	$5,306	$246	$5,155	$252
Small Car	Midsize PC/Perf. PC	$5,892	$223	$5,842	$223	$5,731	$225	$5,692	$226	$5,494	$232
Large Car	Large PC/Perf. PC	$7,180	$225	$7,102	$225	$6,907	$225	$6,822	$225	$6,509	$228
Minivan		$7,198	$206	$7,128	$206	$6,942	$206	$6,864	$206	$6,528	$209
Minivan +towing	Minivan Midsize LT	$7,198	$206	$7,128	$206	$6,942	$206	$6,864	$206	$6,528	$209
Small Truck	Small LT	$6,827	$208	$6,763	$208	$6,592	$209	$6,520	$209	$6,306	$211
Large Truck	Large LT	$7,613	$191	$7,764	$197	$7,557	$197	$7,468	$197	$7,116	$200

Table V-65 MY2025 Direct Manufacturing Costs for EV100 packages at different levels of applied vehicle mass reduction (2009 dollars, markups not included)

EV100 (NMC) @ 450K/yr volume		0% mass reduction		2% mass reduction		7.5% mass reduction		10% mass reduction		20% mass reduction	
EPA Vehicle Class	**NHTSA Vehicle Class**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**
Subcompact	Subcompact PC/Perf. PC Compact PC/Perf. PC	$6,360	$210	$6,316	$211	$6,206	$213	$6,162	$214	$6,074	$216
Small Car	Midsize PC/Perf. PC	$7,001	$198	$6,951	$199	$6,782	$200	$6,727	$201	$6,600	$203
Large Car	Large PC/Perf. PC	$8,101	$190	$8,016	$190	$7,802	$191	$7,711	$191	$7,526	$192
Minivan		$8,414	$180	$8,348	$181	$8,183	$182	$8,116	$183	$7,980	$184
Minivan+towing	Minivan Midsize LT	$8,414	$180	$8,348	$181	$8,183	$182	$8,116	$183	$7,980	$184
Small Truck	Small LT	$8,047	$184	$7,981	$184	$7,825	$186	$7,763	$187	$7,700	$187
Large Truck	Large LT	$9,232	$174	$9,158	$174	$8,970	$175	$8,895	$176	$8,671	$178

Table V-66 MY2025 Direct Manufacturing Costs for EV150 packages at different levels of applied vehicle mass reduction (2009 dollars, markups not included)

EV150 (NMC) @ 450K/yr volume		0% mass reduction		2% mass reduction		7.5% mass reduction		10% mass reduction		20% mass reduction	
EPA Vehicle Class	**NHTSA Vehicle Class**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**	**Pack**	**$/kWh**
Subcompact	Subcompact PC/Perf. PC Compact PC/Perf. PC	$8,292	$182	$8,260	$183	$8,260	$183	$8,260	$183	$8,260	$183
Small Car	Midsize PC/Perf. PC	$9,189	$174	$9,115	$174	$9,115	$174	$9,115	$174	$9,115	$174
Large Car	Large PC/Perf. PC	$10,991	$172	$10,902	$173	$10,902	$173	$10,902	$173	$10,902	$173
Minivan		$11,747	$168	$11,650	$168	$11,650	$168	$11,650	$168	$11,650	$168
Minivan +towing	Minivan Midsize LT	$11,747	$168	$11,650	$168	$11,650	$168	$11,650	$168	$11,650	$168
Small Truck	Small LT	$11,253	$170	$11,253	$170	$11,253	$170	$11,253	$170	$11,253	$170
Large Truck	Large LT	$13,337	$167	$13,227	$168	$13,172	$168	$13,172	$168	$13,172	$168

The agencies then generated linear regressions of battery pack costs against percentage net mass reduction using the costs shown in Table V-59. The regression results are shown in Table V-67. These regression results are used to account for the cost reduction from using a smaller battery due to down-weighting of the vehicle. Detailed discussion of how these results are used can be found in section 0 of this chapter. For P2 HEV battery packs, the direct manufacturing costs shown in Table V-67 are considered applicable to MY 2017. 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 a long-term ICM of 1.35 thereafter. For PHEV and EV battery packs, the direct manufacturing costs shown in Table V-67 are considered applicable to MY2025 because more development work is needed for this technology to have a high penetration in the U.S. market, including research in battery material, safety systems, etc. For the PHEV and EV battery packs, the agencies have applied the learning curve discussed in Section 0 of this chapter. The agencies have applied a “high2” complexity ICM of 1.77 through 2024 then a long-term ICM of 1.50 thereafter.

Table V-67 Linear Regressions of Battery Pack Direct Manufacturing Costs vs Net Mass reduction (2009$)

EPA Vehicle Class	NHSTA Vehicle Class	P2 HEV @MY2017	PHEV20 @MY2025	PHEV40 @MY2025	EV75 @MY2025	EV100 @MY2025	EV150 @MY2025
Subcompact	Subcompact PC/Perf. PC	-$177x+$716	-$862x+$2,602	-$867x+$3,649	-$1,350x+$5,424	-$2,064x+$6,360	-$2,019x+$8,292
	Compact PC/Perf. PC						
Small car	Midsize PC/Perf. PC	-$218x+$758	-$998x+$2,746	-$2,093x+$4,037	-$2,033x+$5,888	-$2,849x+$7,004	-$3,100x+$9,187
Large car	Large PC/Perf. PC	-$300x+$864	-$1,568x+$3,331	-$3,152x+$5,192	-$3,460x+$7,173	-$4,019x+$8,101	-$3,770x+$10,989
Minivan		-$294x+$848	-$1,439x+$3,296	-$2,090x+$5,035	-$3,480x+$7,201	-$3,090x+$8,414	-$4,566x+$11,746
Small truck	Small LT	-$277x+$822	-$1,338x+$3,143	-$2,444x+$4,787	-$3,148x+$6,828	-$2,971x+$8,045	$11,253
Minivan +towing	Minivan Midsize LT	-$294x+$929					
Large truck	Large LT	-$317x+$964					

Notes:

“x” in the equations represents the net mass reduction as a percentage, so a subcompact P2 HEV with a 20% applied weight reduction and, therefore, a 15% net weight reduction would cost (-$177)x(15%)+$716=$689.

The small truck EV150 regression has no slope since the net weight reduction is always 0 due to the 20% weight reduction hit.

The agencies did not regress PHEV or EV costs for the minivan+towing and large truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Non-battery System Costs for MHEVs, HEVs, PHEVs and EVs

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 must be scaled to the vehicle type or class to properly represent the cost. As discussed in the TAR, the agencies derived the costs of these components from the FEV teardown study. 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 Section 0 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 was $14.48 x (motor size in kW) + $763.54. The results are shown as the "Motor assembly" line item in Table V-68,

Table V-69 and Table V-70 which show our scaled DMC for P2 HEV, PHEV20 and PHEV40, respectively.

For EVs, the agencies used the motor and inverter cost regression from the 2010 TAR (see TAR at page B-21). 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 \$8.28x(motor size in kW)+\$181.43. The results are presented as separate line items for "Motor inverter" and "Motor assembly" in Table V-71, Table V-72 and Table V-73 which show our scaled DMC for EV75, EV100 and EV150, respectively.

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* 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 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 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.

The results of the scaling exercise applied to non-battery components are presented in Table V-68 through Table V-73 for P2 HEVs, PHEV20, PHEV40, EV75, EV100 and EV150, respectively.

Table V-68
Scaled Non-battery DMC by Applied Vehicle Weight Reduction for P2 HEV (2009$)

System	Subcompact	Small car	Large car	Minivan	Minivan +towing	Small truck	Large truck
0% WR							
Body system	$6	$6	$6	$7	$7	$6	$7
Brake system	$233	$238	$242	$242	$242	$240	$248
Climate controls	$154	$164	$176	$220	$220	$202	$194
Delete electrical	-$62	-$67	-$85	-$89	-$89	-$89	-$97
DC-DC converter	$115	$126	$157	$167	$167	$167	$183
Power Distr & control	$203	$207	$210	$210	$210	$207	$219
Motor assembly	$1,038	$1,096	$1,342	$1,270	$1,270	$1,212	$1,327
Total	$1,688	$1,771	$2,048	$2,027	$2,027	$1,946	$2,082
2% WR							
Body system	$6	$6	$6	$7	$7	$6	$7
Brake system	$233	$238	$242	$242	$242	$240	$248
Climate controls	$154	$164	$176	$220	$220	$202	$194
Delete electrical	-$62	-$67	-$85	-$89	-$89	-$89	-$97
DC-DC converter	$115	$126	$157	$167	$167	$167	$183
Power Distr & control	$203	$207	$210	$210	$210	$207	$219
Motor assembly	$1,038	$1,096	$1,327	$1,255	$1,255	$1,212	$1,313
Total	$1,688	$1,771	$2,034	$2,013	$2,013	$1,946	$2,067
7.5% WR							
Body system	$6	$6	$6	$7	$7	$6	$7
Brake system	$233	$238	$242	$242	$242	$240	$248
Climate controls	$154	$164	$176	$220	$220	$202	$194
Delete electrical	-$62	-$67	-$85	-$89	-$89	-$89	-$97
DC-DC converter	$115	$126	$157	$167	$167	$167	$183
Power Distr & control	$203	$207	$210	$210	$210	$207	$219
Motor assembly	$1,024	$1,067	$1,298	$1,226	$1,226	$1,183	$1,284
Total	$1,673	$1,742	$2,005	$1,984	$1,984	$1,917	$2,038
10% WR							
Body system	$6	$6	$6	$7	$7	$6	$7
Brake system	$233	$238	$242	$242	$242	$240	$248
Climate controls	$154	$164	$176	$220	$220	$202	$194
Delete electrical	-$62	-$67	-$85	-$89	-$89	-$89	-$97
DC-DC converter	$115	$126	$157	$167	$167	$167	$183
Power Distr & control	$203	$207	$210	$210	$210	$207	$219
Motor assembly	$1,009	$1,067	$1,284	$1,226	$1,226	$1,168	$1,284
Total	$1,659	$1,742	$1,990	$1,984	$1,984	$1,903	$2,038
20% WR							
Body system	$6	$6	$6	$7	$7	$6	$7
Brake system	$233	$238	$242	$242	$242	$240	$248
Climate controls	$154	$164	$176	$220	$220	$202	$194
Delete electrical	-$62	-$67	-$85	-$89	-$89	-$89	-$97
DC-DC converter	$115	$126	$157	$167	$167	$167	$183
Power Distr & control	$203	$207	$210	$210	$210	$207	$219
Motor assembly	$995	$1,053	$1,255	$1,197	$1,197	$1,154	$1,255
Total	$1,644	$1,727	$1,961	$1,955	$1,955	$1,888	$2,009

Table V-69
Scaled Non-battery DMC by Applied Vehicle Weight Reduction for PHEV20 (2009$)[a]

System	Subcompact	Small car	Large car	Minivan	Small truck
0% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$2,151	$2,426	$3,640	$3,279	$3,019
Total	$2,947	$3,249	$4,498	$4,200	$3,911
2% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$2,122	$2,397	$3,583	$3,221	$2,975
Total	$2,918	$3,220	$4,440	$4,142	$3,868
7.5% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$2,036	$2,310	$3,424	$3,091	$2,860
Total	$2,831	$3,133	$4,281	$4,012	$3,752
10% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55

Motor assembly	$2,007	$2,267	$3,351	$3,033	$2,802
Total	$2,802	$3,090	$4,209	$3,954	$3,694
20% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$1,978	$2,238	$3,294	$2,990	$2,744
Total	$2,773	$3,061	$4,151	$3,911	$3,637

[a] The agencies have not estimated PHEV or EV costs for the minivan+towing and large truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table V-70
Scaled Non-battery DMC by Applied Vehicle Weight Reduction for PHEV40 (2009$)

System	Subcompact	Small car	Large car	Minivan	Small truck
0% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$2,151	$2,426	$3,640	$3,279	$3,019
Total	$2,947	$3,249	$4,498	$4,200	$3,911
2% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$2,122	$2,397	$3,583	$3,221	$2,975
Total	$2,918	$3,220	$4,440	$4,142	$3,868
7.5% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$2,050	$2,310	$3,438	$3,106	$2,860
Total	$2,845	$3,133	$4,296	$4,026	$3,752
10% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55

Motor assembly	$2,050	$2,310	$3,438	$3,106	$2,845
Total	$2,845	$3,133	$4,296	$4,026	$3,738
20% WR					
Body system	$6	$6	$6	$7	$6
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
Power Distr & control	$203	$207	$210	$210	$207
On vehicle charger	$103	$103	$103	$103	$103
Supplemental heater	$42	$45	$48	$60	$55
Motor assembly	$2,050	$2,310	$3,438	$3,106	$2,845
Total	$2,845	$3,133	$4,296	$4,026	$3,738

[a] The agencies have not estimated PHEV or EV costs for the minivan+towing and large truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table V-71
Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV75 (2009$)

System	Subcompact	Small car	Large car	Minivan	Small truck
0% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$693	$830	$1,437	$1,256	$1,126
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$1,007	$1,169	$1,887	$1,673	$1,520
Total	$415	$745	$1,254	$1,005	$1,186
2% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$679	$816	$1,408	$1,227	$1,105
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$990	$1,152	$1,853	$1,639	$1,494
Total	$384	$713	$1,191	$942	$1,139
7.5% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$635	$773	$1,328	$1,162	$1,047
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$939	$1,101	$1,759	$1,562	$1,426
Total	$289	$619	$1,017	$800	$1,013

10% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$621	$751	$1,292	$1,134	$1,018
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$922	$1,075	$1,716	$1,528	$1,392
Total	$258	$571	$938	$737	$950
20% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$563	$671	$1,155	$1,018	$946
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$853	$982	$1,554	$1,392	$1,306
Total	$132	$398	$639	$485	$792

a The agencies have not estimated PHEV or EV costs for the minivan+towing and large truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table V-72
Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV100 (2009$)

System	Subcompact	Small car	Large car	Minivan	Small truck
0% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$693	$830	$1,437	$1,256	$1,126
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$1,007	$1,169	$1,887	$1,673	$1,520
Total	$415	$745	$1,254	$1,005	$1,186
2% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$679	$816	$1,408	$1,227	$1,105
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$990	$1,152	$1,853	$1,639	$1,494
Total	$384	$713	$1,191	$942	$1,139
7.5% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$635	$773	$1,328	$1,162	$1,047
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$939	$1,101	$1,759	$1,562	$1,426
Total	$289	$619	$1,017	$800	$1,013
10% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89

DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$621	$751	$1,292	$1,134	$1,018
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$922	$1,075	$1,716	$1,528	$1,392
Total	$258	$571	$938	$737	$950
20% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$599	$715	$1,235	$1,083	$1,004
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$896	$1,033	$1,648	$1,468	$1,374
Total	$210	$493	$812	$627	$918

[a] The agencies have not estimated PHEV or EV costs for the minivan+towing and large truck vehicle classes since we do not believe these vehicle classes would use the technologies.

Table V-73 Scaled Non-battery DMC by Applied Vehicle Weight Reduction for EV150 (2009$)

System	Subcompact	Small car	Large car	Minivan	Small truck
0% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$693	$830	$1,437	$1,256	$1,141
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$1,007	$1,169	$1,887	$1,673	$1,537
Total	$415	$745	$1,254	$1,005	$1,218
2% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$679	$816	$1,408	$1,227	$1,141
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$990	$1,152	$1,853	$1,639	$1,537
Total	$384	$713	$1,191	$942	$1,218
7.5% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$679	$809	$1,401	$1,227	$1,141
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$990	$1,144	$1,844	$1,639	$1,537
Total	$384	$697	$1,175	$942	$1,218
10% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$679	$809	$1,401	$1,227	$1,141
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$990	$1,144	$1,844	$1,639	$1,537
Total	$384	$697	$1,175	$942	$1,218

20% WR					
Brake system	$233	$238	$242	$242	$240
Climate controls	$154	$164	$176	$220	$202
Delete electrical	-$62	-$67	-$85	-$89	-$89
DC-DC converter	$115	$126	$157	$167	$167
High voltage wiring	$203	$207	$210	$210	$207
Supplemental heater	$85	$90	$97	$120	$110
On vehicle charger	$309	$309	$309	$309	$309
Motor inverter	$679	$809	$1,401	$1,227	$1,141
Controls	$119	$119	$119	$119	$119
Delete IC engine	-$1,565	-$1,565	-$2,418	-$2,347	-$1,849
Delete transmission	-$877	-$877	-$877	-$877	-$877
Motor assembly	$990	$1,144	$1,844	$1,639	$1,537
Total	$384	$697	$1,175	$942	$1,218

[a] The agencies have not estimated PHEV or EV costs for the minivan+towing and large 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 **V-74**. This was done using the same weight reduction offsets as used for battery packs as presented in

Table V-60. These regression results are used to account for the cost reduction from using a smaller battery due to down-weighting of the vehicle. Detailed discussion of how these results are used can be found in section 0 of this chapter. 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 V-74 Linear Regressions of Non-Battery System Direct Manufacturing Costs vs Net Mass reduction (2009$)

EPA Vehicle Class	NHSTA Vehicle Class	P2 HEV @MY2012	PHEV20 @MY2012	PHEV40 @MY2012	EV75 @MY2017	EV100 @MY2017	EV150 @MY2017
Subcompact	Subcompact PC/Perf. PC Compact PC/Perf. PC	-$323x+$1,691	-$1,478x+$2,946	-$1,473x+$2,947	-$1,505x+$411	-$1,535x+$413	-$1,976x+$415
Small car	Midsize PC/Perf. PC	-$321x+$1,771	-$1,603x+$3,251	-$1,613x+$3,250	-$1,803x+$749	-$1,787x+$748	-$1,924x+$746
Large car	Large PC/Perf. PC	-$581x+$2,046	-$2,930x+$4,499	-$2,860x+$4,498	-$3,181x+$1,255	-$3,137x+$1,253	-$3,278x+$1,254
Minivan		-$466x+$2,024	-$2,433x+$4,196	-$2,441x+$4,196	-$2,687x+$1,002	-$2,696x+$1,002	-$2,969x+$1,005
Small truck	Small LT	-$428x+$1,948	-$2,186x+$3,912	-$2,201x+$3,912	-$2,390x+$1,188	-$2,383x+$1,187	$x+$1,218
Minivan +towing	Minivan Midsize LT	-$492x+$2,024					
Large truck	Large LT	-$488x+$2,079					

Notes:
"x" in the equations represents the net mass reduction as a percentage, so a subcompact P2 HEV with a 20% applied weight reduction and, therefore, a 15% net weight reduction would cost (-$323)x(15%)+$1691=$1643.
The agencies did not regress PHEV or EV costs for the minivan+towing and large truck vehicle classes since we do not believe these vehicle classes would use the technologies.

For P2 HEV non-battery components, the direct manufacturing costs shown in

Table **V-74** are considered applicable to MY 2017. 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 a long-term ICM of 1.35 thereafter. For PHEV and EV non-battery components, the direct manufacturing costs shown in

Table **V-74** are considered applicable to MY 2025. 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 a long-term ICM of 1.50 thereafter.

How Did NHTSA Account for the Cost Synergy between Mass Reduction and Electrification System in CAFE Model?

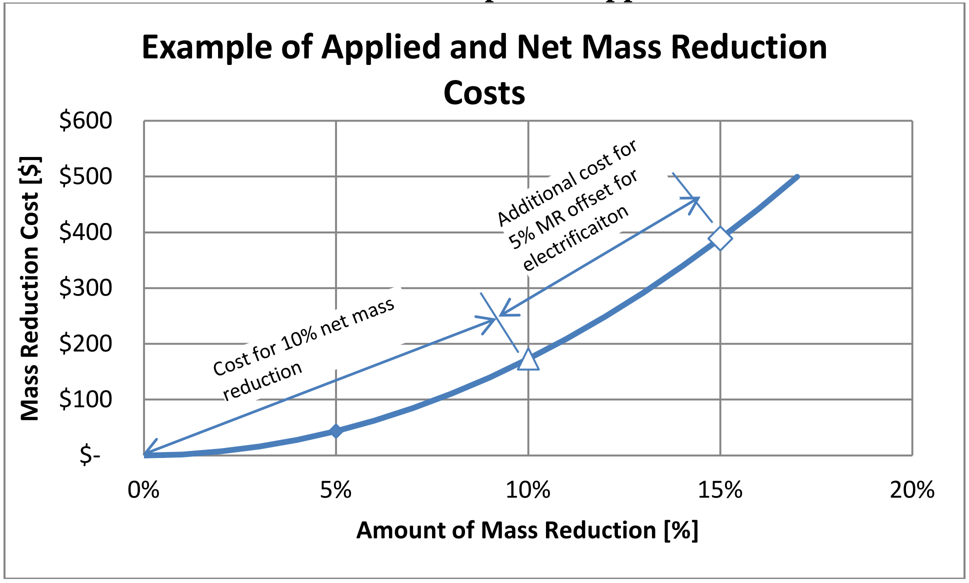
Because the CAFE model does not use pre-built packages and applies technologies individually as necessary to meet the fuel consumption reduction requirement, cost interaction between any particular technology and other technologies has to be flexible so that when a technology is picked, the model will automatically look through the cost synergy defined in a table and apply cost adjustment 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
(4) Table V-60. 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
(5) Figure V-20 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.
(6) Electrification system cost synergy (battery and non-battery components) due to mass reduction as defined in Table V-67 and
(7) Table **V-74**: Continuing the example in the steps above, if a midsize passenger car

needs both 10 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 V-67 and
(8) Table **V-74**. 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 a negative, *i.e.*, cost
reduction, due to the downsizing of electrification system resulting from mass
reduction.

The sum of item (3) and (4) in the above list are calculate as cost synergy and store in the cost synergy table as defined Section 0.

Figure V-20 Mass Reduction Cost Example for Applied and Net Mass Reduction



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 on this issue, 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 V-75 below.

Table V-75: 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: [204],[205], [206], [207]

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[204] Morrow, Karner, and Francfort, "Plug-in Hybrid Electric Vehicle Charging Infrastructure Review," INL/EXT-08-15058, November 2008. Docket No. NHTSA-2010-0131 or Available at http://avt.inel.gov/pdf/phev/phevInfrastructureReport08.pdf (last accessed November 14, 2011)

[205] May and Mattila, "Plugging In: A Stakeholder Investment Guide for Public Electric-Vehicle Charging Infrastructure," Rocky Mountain Institute, July 2009, Docket No. NHTSA-2010-0131 or Available at http://projectgetready.com/docs/Plugging%20In%20-%20A%20Stakeholder%20Investment%20Guide.pdf (last accessed November 14, 2011)

[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.

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 V-76 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 no 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.

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[206] ETEC, 2009.

[207] Electrification Coalition, “Electrification Roadmap”, November 2009. Available at http://www.electrificationcoalition.org/electrification-roadmap.php. (last accessed November 14, 2011) Also in Docket NHTSA-2010-0131.

Table V-76: Charger Type by Vehicle Technology and Class

NHTSA Vehicle Class	PHEV20		PHEV40		EV75		EV100		EV150	
	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2
Subcompact PC/Perf. PC Compact PC/Perf. PC	100%	-	25%	75%	-	100%	-	100%	-	100%
Midsize PC/Perf. PC	100%	-	10%	90%	-	100%	-	100%	-	100%
Large PC/Perf. PC	100%	-	-	100%	-	100%	-	100%	-	100%
Minivan Midsize LT	100%	-	-	100%	-	100%	-	100%	-	100%
Small LT	100%	-	-	100%	-	100%	-	100%	-	100%
Large LT	50%	50%	-	100%	-	100%	-	100%	-	100%

For this 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 $30 (2009$) based on typical costs of similar electrical equipment sold to consumers today and that for a level 2 charger at $202 (2009$). Labor associated with installing either of these chargers is estimated at $1,009 (2009$). 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 subcompacts would be charged with a level 1 charger with the remainder charged via a level 2 charger; 10% of small 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 19 as presented in Section 0 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.

P2 Hybrid

A P2 hybrid is a vehicle with an electric drive motor 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. The P2 Hybrid is a newly emerging hybrid technology that uses a transmission integrated electric motor placed between the engine and a gearbox or CVT, much like the IMA system described above except 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. 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, when combined with a DCT transmission, reduces gear-train losses relative to PSHEV or 2MHEV systems. 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 we will see in the timeframe of this rule. The agencies could have equally chosen the power-split architecture as the representative HEV architecture. These two HEVs have similar average effectiveness values (combined city and highway fuel economy), though the P2 systems may have lower cost due to the lower number of parts and complexity.

Thus, 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 is an example of a P2 hybrid currently in production and available to consumers. While generally positive, some early reviews have specifically critiqued the drivability of the vehicle.[208] 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. NHTSA seeks comment regarding the potential of P2 hybrids to overcome these issues or others, and we specifically seek 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.

The effectiveness used for vehicle packages with the P2-hybrid configuration within this analysis reflects what the agencies believe to be a conservative estimate of system performance. Vehicle simulation modeling of technology packages using the P2 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 NPRM analysis. Based on the recent Ricardo study, the effectiveness for P2 hybrid used in this NPRM 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 relative to the baseline vehicle. This represents an increase in strong HEV effectiveness of approximately 2 percent as compared to the estimate employed in the MYs 2012-2016 final rule based on published data for new HEVs that have

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[208] Car and Driver praised the Sonata's fuel economy but followed with "the integration of the hybrid system is far less impressive" (June, 2011), while Edmunds.com criticized the "clumsy braking response" (http://www.edmunds.com/hyundai/sonata-hybrid/2011/, last accessed Nov. 3, 2011). Other reviews have indicated that the driveability issues are more pronounced when the vehicle is in fuel-efficient "Blue Mode." *See, e.g.*, http://www.cars.com/hyundai/sonata-hybrid/2011/expert-reviews/?revid=56695(last accessed Nov. 3, 2011).

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). Additionally, for the Large Car, Minivan, and Small Truck subclasses for this NPRM analysis, the agencies estimated that HEV effectiveness could be increased by allowing for down-powering of the gasoline engine. This could impact the towing capacity for some vehicles when converted to a HEV powertrain.[209] The agencies believe that consumers interested in these vehicles who require towing capacity could acquire it by purchasing a vehicle with a non-hybrid powertrain (as they do today).[210] The approach used by the agencies allows more HEV and engine down-powering being applied to vehicle fleet, 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.[211] 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.

The costs for P2 hybrids without mass reduction as used in the Volpe model are listed in

Table V-77. 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 0. The agencies have applied a high complexity ICM to both the battery and non-battery component costs for P2 hybrids, although the timing of the ICMs varies: for the battery components in P2 hybrids, the ICM switches from the short-term value of 1.56 to the long-term value of 1.35 in 2024, while for the non-battery component the switch to long-term ICMs happens in 2018.

Table V-77 NHTSA Costs for P2 Hybrid Applied in Volpe Model without Mass Reduction (2009$)

Tech.	Cost type	NHTSA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$716	$695	$674	$654	$634	$615	$597	$579	$561
Battery		Midsize PC/Perf PC	$758	$735	$713	$692	$671	$651	$631	$612	$594
Battery	DMC	Large PC/Perf PC	$864	$838	$813	$788	$765	$742	$719	$698	$677
Battery	DMC	Midsize LT Minivan	$929	$901	$874	$848	$822	$798	$774	$750	$728
Battery	DMC	Small LT	$822	$797	$773	$750	$728	$706	$685	$664	$644

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[209] At issue are those small SUVs and Minivans with a towing capacity of at least 3500 lbs when equipped with an OEM or dealer installed towing package. While their towing capacity should be maintained, they may see a performance degradation in the event that the motive power is delivered exclusively by the gasoline engine which could occur during an extended uphill drive at maximum capacity.

[210] 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 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 could offset the potential increase in fuel consumption and CO_2 emissions resulting from consumers selecting the higher-performance non-hybrid powertrain vehicles.

[211] 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.

Battery	DMC	Large LT	$964	$935	$907	$880	$854	$828	$803	$779	$756
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$1,467	$1,438	$1,409	$1,381	$1,353	$1,326	$1,300	$1,274	$1,248
Non-battery	DMC	Midsize PC/Perf PC	$1,537	$1,506	$1,476	$1,446	$1,417	$1,389	$1,361	$1,334	$1,307
Non-battery	DMC	Large PC/Perf PC	$1,775	$1,739	$1,705	$1,671	$1,637	$1,604	$1,572	$1,541	$1,510
Non-battery	DMC	Midsize LT Minivan	$1,756	$1,721	$1,687	$1,653	$1,620	$1,588	$1,556	$1,525	$1,494
Non-battery	DMC	Small LT	$1,690	$1,656	$1,623	$1,591	$1,559	$1,528	$1,497	$1,467	$1,438
Non-battery	DMC	Large LT	$1,803	$1,767	$1,732	$1,697	$1,663	$1,630	$1,597	$1,566	$1,534
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$404	$402	$401	$400	$398	$397	$396	$395	$242
Battery	IC	Midsize PC/Perf PC	$427	$426	$424	$423	$421	$420	$419	$418	$257
Battery	IC	Large PC/Perf PC	$487	$485	$483	$482	$480	$479	$477	$476	$292
Battery	IC	Midsize LT Minivan	$523	$522	$520	$518	$517	$515	$513	$512	$314
Battery	IC	Small LT	$463	$462	$460	$459	$457	$456	$454	$453	$278
Battery	IC	Large LT	$543	$542	$540	$538	$536	$535	$533	$531	$326
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$939	$937	$575	$574	$573	$572	$572	$571	$570
Non-battery	IC	Midsize PC/Perf PC	$983	$981	$602	$601	$601	$600	$599	$598	$597
Non-battery	IC	Large PC/Perf PC	$1,136	$1,133	$696	$695	$694	$693	$692	$691	$690
Non-battery	IC	Midsize LT Minivan	$1,124	$1,121	$688	$687	$686	$685	$684	$683	$682
Non-battery	IC	Small LT	$1,081	$1,079	$663	$662	$661	$660	$659	$658	$657
Non-battery	IC	Large LT	$1,154	$1,151	$707	$706	$705	$704	$703	$702	$701
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$1,120	$1,097	$1,075	$1,053	$1,032	$1,012	$992	$973	$804
Battery	TC	Midsize PC/Perf PC	$1,185	$1,161	$1,137	$1,114	$1,092	$1,071	$1,050	$1,030	$850
Battery	TC	Large PC/Perf PC	$1,350	$1,323	$1,296	$1,270	$1,245	$1,220	$1,197	$1,174	$969
Battery	TC	Midsize LT Minivan	$1,452	$1,423	$1,394	$1,366	$1,339	$1,313	$1,287	$1,262	$1,042
Battery	TC	Small LT	$1,285	$1,259	$1,233	$1,209	$1,185	$1,162	$1,139	$1,117	$922
Battery	TC	Large LT	$1,508	$1,477	$1,447	$1,418	$1,390	$1,363	$1,336	$1,311	$1,082
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$2,406	$2,375	$1,984	$1,955	$1,927	$1,899	$1,871	$1,845	$1,818
Non-battery	TC	Midsize PC/Perf PC	$2,520	$2,487	$2,078	$2,048	$2,018	$1,989	$1,960	$1,932	$1,904
Non-battery	TC	Large PC/Perf PC	$2,911	$2,873	$2,401	$2,365	$2,331	$2,297	$2,264	$2,232	$2,200
Non-battery	TC	Midsize LT Minivan	$2,880	$2,843	$2,375	$2,340	$2,306	$2,273	$2,240	$2,208	$2,177
Non-battery	TC	Small LT	$2,772	$2,736	$2,286	$2,252	$2,220	$2,187	$2,156	$2,125	$2,095
Non-battery	TC	Large LT	$2,957	$2,919	$2,439	$2,403	$2,368	$2,334	$2,300	$2,267	$2,235

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Power Split Hybrid

Power-split hybrid (PSHEV) is a hybrid electric drive system that replaces the traditional transmission with a single planetary gear set and a motor/generator. This motor/generator uses the engine to either charge the battery or to supply additional power to the drive motor. A 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 proposal.

Power-split hybrid technology is currently in production and used on vehicles, such as Toyota Prius, but the agencies have chosen not to apply it this NPRM analysis because a more cost-effective hybrid technology, P2 hybrid, is applied instead as described in the previous section.

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 at highway speeds relative to other types of hybrid electric drive systems.

2-mode hybrid technology exists in the baseline fleet, and OEMs have used 2-mode hybrids on vehicles with towing requirements, such as the Chevy Tahoe and the Dodge Ram pickup truck. However, the agencies have chosen not to apply it in this NPRM analysis, because a more cost-effective hybrid technology, P2 hybrid, is applied instead as described in the previous section. The agencies may re-consider this hybrid technology in vehicles with towing requirements, such as pickup trucks, in the final rule, based on comments received and new information obtained.

Plug-in Electrical Hybrid Vehicles (PHEV)

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 V-78 below, illustrates how PHEVs compare functionally to both hybrid electric vehicles (HEV) and electric vehicles (EV). These characteristics can change significantly within each class/subclass, so this is simply meant as an illustration of the general characteristics. In reality, the design options are so varied that all of these vehicles exist on a continuum, with HEVs on one end and EVs on the other.

Table V-78 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 electricity generation during “off-peak” periods (such as 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. Additionally, 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 electricity generation can be accounted for if a full upstream and downstream analysis is desired. These effects are considered in NHTSA’s assessment of the benefits of this rulemaking, *see* Chapter VIII below, but they are not considered directly for purposes of determining the effectiveness of the technologies at improving fuel economy.

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 systems and the larger expensive battery pack.

Because PHEVs are just starting to enter the marketplace, fuel economy estimates for these vehicles remain difficult to obtain for purposes of this analysis. NHTSA therefore based the effectiveness estimations for PHEVs and EVs on experimental data. When evaluating the effectiveness of PHEVs and EVs at reducing fuel consumption, NHTSA referenced the UDDS and highway fuel economy data of 3 pairs of vehicles for which NHTSA has fuel economy data in the CAFE database:

- The MiniE electric vehicle and the gasoline-powered Mini with automatic transmission,

- The Tesla Roadster electric vehicle and the gasoline-powered rear-wheel-drive Lotus Elise Sedan with a 6-speed manual transmission,[212] and
- The MY 2012 Nissan Leaf electric vehicle and the gasoline-powered Nissan Sentra with automatic transmission.[213]

The fuel economy and fuel consumption for the first two pairs are shown in Table V-79; the agency was unable to show the information for the last pair because the information for the Nissan Leaf is confidential.

Table V-79 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

Because technologies are applied in the CAFE model in an incremental manner, the effectiveness for each technology is incremental to the previous technology on the decision tree. 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. In order to calculate the effectiveness of the PHEV technology for purposes of CAFE analysis, operation on both gasoline and electricity has to be considered.

First, the incremental fuel economy benefit for gasoline operation is determined using the incremental effectiveness of strong hybrid (SHEV) from the LPM, which indicates that the incremental effectiveness for SHEV is 46.2 percent. For example, the fuel economy for Mini Gas ATX is 38.6 mpg. Applying the 46.2 percent fuel consumption reduction, the fuel economy for an SHEV Mini can be calculated as follows.

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.

Next, the petroleum-equivalent fuel economy for electric operation for the PHEV is set to be equal to the measured fuel economy of an example EV, *i.e.*, 342.4 mpg in the case of the Mini E.

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[212] The Tesla Roadster is based on the Lotus Elise body, which makes the Elise the most comparable vehicle to the Roadster for purposes of this analysis.

[213] Sentra is used as the baseline for Leaf comparison because these two vehicles are of similar size from the same manufacturer.

And finally, the fuel economy benefit from the gasoline operation and the fuel economy benefit from electric operation need to be combined. Through MY 2019, for compliance purposes, the statute requires the fuel economy of PHEVs to be calculated assuming that 50 percent of the operation is on electricity and 50 percent on gasoline,[214] so a combination reflecting a 50-50 split is potentially one place to start. It can also be helpful to consider how much of a PHEV's operation is electric, as gauged by the charge-depleting range. Since the charge-depleting range varies for different PHEV designs, NHTSA chose to evaluate a range of approximately 30 miles, which is also close to the range identified in SAE Standard J1711 as having a 0.5 utility factor,[215] which is equivalent to the 50-50 weighting of gasoline and electric operation required by statute through MY 2019.

NHTSA thus calculated the combined fuel economy for PHEV for purposes of this analysis using a 50-50 weighting factor, as follows:

The incremental fuel consumption reduction for PHEV is then calculated relative to SHEV. Using the example of Mini E, the incremental fuel consumption reduction for PHEV relative to SHEV is 39.5 percent, as shown below:

Table V-80 lists NHTSA's incremental effectiveness calculation for two pairs of vehicles, the Mini E and the Tesla Roadster. Again, the table does not contain an incremental fuel consumption calculation for PHEV based on the Nissan Leaf due to the confidentiality of that vehicle's current fuel economy rating for compliance purposes. The derived incremental effectiveness for Nissan Leaf is 40.6 percent. Together, the average incremental effectiveness of these three pairs of vehicles is 40.65 percent, which is the number used by NHTSA in the CAFE modeling for this NPRM.

Table V-80 Incremental Effectiveness Calculation for purposes of CAFE modeling

Mini E

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[214] *See* 49 U.S.C. § 32905.

[215] SAE Standard J1711 assigns a 0.5 utility factor to vehicles with a charge-depleting range of 27.4-28.2 miles.

	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.

Using that formula, the average effectiveness for the three pairs of vehicles is 68.54 percent, which is the value used in the analysis for this NPRM.

The cost of PHEV consists of three parts: the cost for the battery, the cost for the non-battery systems (including, for example, the gasoline engine and transmission), and the cost for the charger and the labor to install it. Costs for PHEVs without mass reduction as used in the Volpe model are listed in Table V-79 to Table V-81. NHTSA accounts for the cost synergy due to the interaction between mass reduction and sizing of the electrification system (battery and non-battery system) as described in section 0 of this chapter. EPA developed costs for a PHEV20 and a PHEV40 with the methodologies discussed in section 0; because NHTSA modeled a PHEV 30 for this proposal, NHTSA averaged EPA's direct costs for the PHEV20 and the PHEV40.

For indirect costs, a high complexity ICM is used for the non-battery component costs for PHEVs and PHEV chargers, which switches from the short-term value of 1.56 to the long-term value of 1.35 at 2018. A higher ICM factor is used for PHEV batteries due to the fact that they represent a more complex technology. The ICM for PHEV batteries switches from the short-term value of 1.77 to the long-term value of 1.50 at 2024.

Table V-81 NHTSA Costs for PHEV20 Applied in the Volpe Model with No Mass Reduction (2009$)

Tech.	Cost type	NHTSA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$5,082	$4,066	$4,066	$3,253	$3,253	$3,253	$3,253	$3,253	$2,602
Battery		Midsize PC/Perf PC	$5,363	$4,291	$4,291	$3,433	$3,433	$3,433	$3,433	$3,433	$2,746
Battery	DMC	Large PC/Perf PC	$6,505	$5,204	$5,204	$4,163	$4,163	$4,163	$4,163	$4,163	$3,331
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$2,556	$2,505	$2,455	$2,406	$2,358	$2,311	$2,264	$2,219	$2,175
Non-battery	DMC	Midsize PC/Perf PC	$2,820	$2,764	$2,709	$2,654	$2,601	$2,549	$2,498	$2,448	$2,399
Non-battery	DMC	Large PC/Perf PC	$3,903	$3,825	$3,749	$3,674	$3,600	$3,528	$3,458	$3,389	$3,321
Charger	DMC	All	$59	$47	$47	$38	$38	$38	$38	$38	$30
Charger Labor	DMC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$2,186	$2,112	$2,112	$2,052	$2,052	$2,052	$2,052	$2,052	$1,292
Battery	IC	Midsize PC/Perf PC	$2,307	$2,228	$2,228	$2,165	$2,165	$2,165	$2,165	$2,165	$1,364
Battery	IC	Large PC/Perf PC	$2,798	$2,703	$2,703	$2,626	$2,626	$2,626	$2,626	$2,626	$1,654
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$1,635	$1,632	$1,002	$1,000	$999	$997	$996	$995	$993
Non-battery	IC	Midsize PC/Perf PC	$1,804	$1,801	$1,106	$1,104	$1,102	$1,101	$1,099	$1,097	$1,096
Non-battery	IC	Large PC/Perf PC	$2,497	$2,492	$1,530	$1,528	$1,525	$1,523	$1,521	$1,519	$1,517
Charger	IC	All	$19	$18	$18	$17	$17	$17	$17	$17	$10
Charger Labor	IC	All	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$7,269	$6,177	$6,177	$5,304	$5,304	$5,304	$5,304	$5,304	$3,894
Battery	TC	Midsize PC/Perf PC	$7,671	$6,519	$6,519	$5,598	$5,598	$5,598	$5,598	$5,598	$4,110
Battery	TC	Large PC/Perf PC	$9,303	$7,907	$7,907	$6,789	$6,789	$6,789	$6,789	$6,789	$4,985
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$4,191	$4,137	$3,457	$3,406	$3,357	$3,308	$3,260	$3,214	$3,168
Non-battery	TC	Midsize PC/Perf PC	$4,625	$4,565	$3,814	$3,758	$3,704	$3,650	$3,597	$3,546	$3,495
Non-battery	TC	Large PC/Perf PC	$6,401	$6,318	$5,279	$5,202	$5,126	$5,052	$4,979	$4,907	$4,837
Charger	TC	All	$77	$65	$65	$55	$55	$55	$55	$55	$40
Charger Labor	TC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table V-82 NHTSA Costs for PHEV40 Applied in the Volpe Model with No Mass Reduction (2009$)

Tech.	Cost type	NHTSA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$7,126	$5,701	$5,701	$4,561	$4,561	$4,561	$4,561	$4,561	$3,649
Battery		Midsize PC/Perf PC	$7,884	$6,307	$6,307	$5,046	$5,046	$5,046	$5,046	$5,046	$4,037
Battery	DMC	Large PC/Perf PC	$10,140	$8,112	$8,112	$6,490	$6,490	$6,490	$6,490	$6,490	$5,192
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$2,557	$2,506	$2,455	$2,406	$2,358	$2,311	$2,265	$2,220	$2,175
Non-battery	DMC	Midsize PC/Perf PC	$2,820	$2,763	$2,708	$2,654	$2,601	$2,549	$2,498	$2,448	$2,399
Non-battery	DMC	Large PC/Perf PC	$3,902	$3,824	$3,748	$3,673	$3,599	$3,527	$3,457	$3,388	$3,320
Charger	DMC	All	$357	$286	$286	$229	$229	$229	$229	$229	$183
Charger Labor	DMC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$3,066	$2,112	$2,112	$2,052	$2,052	$2,052	$2,052	$2,052	$1,292
Battery	IC	Midsize PC/Perf PC	$3,392	$2,228	$2,228	$2,165	$2,165	$2,165	$2,165	$2,165	$1,364
Battery	IC	Large PC/Perf PC	$4,362	$2,703	$2,703	$2,626	$2,626	$2,626	$2,626	$2,626	$1,654
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$1,636	$1,632	$1,002	$1,001	$999	$998	$996	$995	$993
Non-battery	IC	Midsize PC/Perf PC	$1,804	$1,800	$1,105	$1,104	$1,102	$1,100	$1,099	$1,097	$1,096
Non-battery	IC	Large PC/Perf PC	$2,496	$2,491	$1,530	$1,527	$1,525	$1,523	$1,520	$1,518	$1,516
Charger	IC	All	$114	$110	$110	$106	$106	$106	$106	$106	$63
Charger Labor	IC	All	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$10,191	$7,812	$7,812	$6,612	$6,612	$6,612	$6,612	$6,612	$4,941
Battery	TC	Midsize PC/Perf PC	$11,276	$8,536	$8,536	$7,211	$7,211	$7,211	$7,211	$7,211	$5,400
Battery	TC	Large PC/Perf PC	$14,502	$10,815	$10,815	$9,116	$9,116	$9,116	$9,116	$9,116	$6,846
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$4,192	$4,138	$3,458	$3,407	$3,357	$3,309	$3,261	$3,214	$3,168
Non-battery	TC	Midsize PC/Perf PC	$4,624	$4,564	$3,813	$3,758	$3,703	$3,649	$3,596	$3,545	$3,494
Non-battery	TC	Large PC/Perf PC	$6,399	$6,316	$5,277	$5,200	$5,124	$5,050	$4,977	$4,906	$4,836
Charger	TC	All	$472	$396	$396	$335	$335	$335	$335	$335	$246
Charger Labor	TC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table V-83 NHTSA Costs Applied in Volpe Model for PHEV30 with No Mass Reduction (2009$)

Tech.	Cost type	NHTSA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$6,104	$4,883	$4,883	$3,907	$3,907	$3,907	$3,907	$3,907	$3,125
Battery		Midsize PC/Perf PC	$6,624	$5,299	$5,299	$4,239	$4,239	$4,239	$4,239	$4,239	$3,391
Battery	DMC	Large PC/Perf PC	$8,323	$6,658	$6,658	$5,327	$5,327	$5,327	$5,327	$5,327	$4,261
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$2,556	$2,505	$2,455	$2,406	$2,358	$2,311	$2,265	$2,219	$2,175
Non-battery	DMC	Midsize PC/Perf PC	$2,820	$2,764	$2,708	$2,654	$2,601	$2,549	$2,498	$2,448	$2,399
Non-battery	DMC	Large PC/Perf PC	$3,903	$3,825	$3,748	$3,673	$3,600	$3,528	$3,457	$3,388	$3,320
Charger	DMC	All	$208	$166	$166	$133	$133	$133	$133	$133	$107
Charger Labor	DMC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$2,626	$2,112	$2,112	$2,052	$2,052	$2,052	$2,052	$2,052	$1,292
Battery	IC	Midsize PC/Perf PC	$2,849	$2,228	$2,228	$2,165	$2,165	$2,165	$2,165	$2,165	$1,364
Battery	IC	Large PC/Perf PC	$3,580	$2,703	$2,703	$2,626	$2,626	$2,626	$2,626	$2,626	$1,654
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$1,635	$1,632	$1,002	$1,001	$999	$998	$996	$995	$993
Non-battery	IC	Midsize PC/Perf PC	$1,804	$1,800	$1,105	$1,104	$1,102	$1,100	$1,099	$1,097	$1,096
Non-battery	IC	Large PC/Perf PC	$2,497	$2,492	$1,530	$1,528	$1,525	$1,523	$1,521	$1,518	$1,516
Charger	IC	All	$67	$64	$64	$62	$62	$62	$62	$62	$37
Charger Labor	IC	All	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$8,730	$6,995	$6,995	$5,958	$5,958	$5,958	$5,958	$5,958	$4,418
Battery	TC	Midsize PC/Perf PC	$9,473	$7,527	$7,527	$6,404	$6,404	$6,404	$6,404	$6,404	$4,755
Battery	TC	Large PC/Perf PC	$11,903	$9,361	$9,361	$7,952	$7,952	$7,952	$7,952	$7,952	$5,915
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$4,192	$4,137	$3,457	$3,407	$3,357	$3,308	$3,261	$3,214	$3,168
Non-battery	TC	Midsize PC/Perf PC	$4,624	$4,564	$3,814	$3,758	$3,703	$3,649	$3,597	$3,545	$3,495
Non-battery	TC	Large PC/Perf PC	$6,400	$6,317	$5,278	$5,201	$5,125	$5,051	$4,978	$4,907	$4,837
Charger	TC	All	$275	$230	$230	$195	$195	$195	$195	$195	$143
Charger Labor	TC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Electric Vehicle (EV)

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 2012-2016 final rule analysis did not anticipate a significant penetration of EVs, in this analysis, EVs with several

different ranges have been included. As discussed in the section above for PHEVs, NHTSA uses DOE's petroleum equivalency factor in calculating the fuel economy effectiveness for EVs, since electric operation does not involve miles per gallon.
Using the fuel economy of the PHEV calculated as shown in the previous section, the effectiveness of EV incremental to PHEV can be calculated similarly using the formula below.

The average effectiveness for the three pairs of EVs of 68.54 percent is used in CAFE modeling as incremental effectiveness relative to PHEVs.

For battery costs, NHTSA assumes 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 percent of the nominal battery pack capacity. NHTSA considered both a 75-mile range EV (EV75) and a 150-mile range EV (EV150) in this NPRM analysis. The EV75 was employed to represent costs relevant to vehicles sold to "early adopters." We assumed that as this technology is entering the market, the OEM will try to keep costs low at the beginning to spur the technology, which, given the high cost of the battery packs at this early stage of EVs, will require the battery pack size to be limited to reduce cost. Larger battery packs to address "range anxiety" concerns should not be necessary at this stage, since we assume that early adopters tend to be urban drivers. The EV150 was employed to represent costs relevant to vehicles sold later in the rulemaking, to non-early adopters. We assumed that as the technology develops and as the market penetration increases, OEMs would need to provide a longer driving range to meet consumer expectations.

The cost of an EV consists of three parts: the cost of the battery pack, the cost of non-battery systems, and the cost of a charger and charger installation labor. A high complexity ICM was applied to the non-battery component cost for EVs and EV chargers, which switches from the short-term value of 1.56 to the long-term value of 1.35 at 2018. A higher ICM factor was applied to EV batteries due to the fact that they represent a more complex technology. The ICM for EV battery switches from the short-term value of 1.77 to the long-term value of 1.50 at 2024. The costs of EVs without mass reduction as applied in the CAFE model for this analysis are listed in Table V-84 to

Table V-86. NHTSA accounts for the cost synergy due to the interaction between mass reduction and sizing of the electrification system (battery and non-battery system) as described in section 0.

Table V-84 NHTSA Costs Applied in Volpe Model for EV75 with No Mass Reduction (2009$)

Tech.	Cost type	NHTSA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$10,594	$8,475	$8,475	$6,780	$6,780	$6,780	$6,780	$6,780	$5,424
Battery		Midsize PC/Perf PC	$11,500	$9,200	$9,200	$7,360	$7,360	$7,360	$7,360	$7,360	$5,888
Battery	DMC	Large PC/Perf PC	$14,009	$11,207	$11,207	$8,966	$8,966	$8,966	$8,966	$8,966	$7,173
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$411	$399	$387	$375	$364	$353	$346	$339	$332
Non-battery	DMC	Midsize PC/Perf PC	$749	$727	$705	$684	$663	$643	$630	$618	$605
Non-battery	DMC	Large PC/Perf PC	$1,255	$1,217	$1,181	$1,145	$1,111	$1,077	$1,056	$1,035	$1,014
Charger	DMC	All	$391	$313	$313	$250	$250	$250	$250	$250	$200
Charger Labor	DMC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$4,557	$4,401	$4,401	$4,277	$4,277	$4,277	$4,277	$4,277	$2,694
Battery	IC	Midsize PC/Perf PC	$4,947	$4,778	$4,778	$4,642	$4,642	$4,642	$4,642	$4,642	$2,924
Battery	IC	Large PC/Perf PC	$6,027	$5,820	$5,820	$5,655	$5,655	$5,655	$5,655	$5,655	$3,562
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$317	$316	$315	$314	$313	$312	$312	$311	$200
Non-battery	IC	Midsize PC/Perf PC	$577	$575	$574	$572	$570	$569	$568	$567	$365
Non-battery	IC	Large PC/Perf PC	$966	$963	$961	$958	$956	$953	$952	$950	$611
Charger	IC	All	$114	$110	$110	$106	$106	$106	$106	$106	$63
Charger Labor	IC	All	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$15,152	$12,877	$12,877	$11,057	$11,057	$11,057	$11,057	$11,057	$8,118
Battery	TC	Midsize PC/Perf PC	$16,447	$13,978	$13,978	$12,002	$12,002	$12,002	$12,002	$12,002	$8,812
Battery	TC	Large PC/Perf PC	$20,036	$17,028	$17,028	$14,621	$14,621	$14,621	$14,621	$14,621	$10,735
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$728	$714	$702	$689	$677	$665	$658	$650	$533
Non-battery	TC	Midsize PC/Perf PC	$1,326	$1,302	$1,278	$1,256	$1,234	$1,212	$1,198	$1,185	$970
Non-battery	TC	Large PC/Perf PC	$2,221	$2,180	$2,141	$2,103	$2,066	$2,031	$2,007	$1,985	$1,625
Charger	TC	All	$505	$422	$422	$356	$356	$356	$356	$356	$263
Charger Labor	TC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table V-85 NHTSA Costs for EV100 Applied in Volpe Model with No Mass Reduction (2009$)

Tech.	Cost	NHTSA Vehicle	2017	2018	2019	2020	2021	2022	2023	2024	2025

	type	**Class**									
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$12,422	$9,938	$9,938	$7,950	$7,950	$7,950	$7,950	$7,950	$6,360
Battery		Midsize PC/Perf PC	$13,679	$10,943	$10,943	$8,755	$8,755	$8,755	$8,755	$8,755	$7,004
Battery	DMC	Large PC/Perf PC	$15,823	$12,658	$12,658	$10,127	$10,127	$10,127	$10,127	$10,127	$8,101
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$413	$400	$388	$377	$365	$354	$347	$340	$334
Non-battery	DMC	Midsize PC/Perf PC	$748	$726	$704	$683	$662	$642	$630	$617	$605
Non-battery	DMC	Large PC/Perf PC	$1,253	$1,216	$1,179	$1,144	$1,109	$1,076	$1,055	$1,033	$1,013
Charger	DMC	All	$391	$313	$313	$250	$250	$250	$250	$250	$200
Charger Labor	DMC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$5,344	$5,161	$5,161	$5,015	$5,015	$5,015	$5,015	$5,015	$3,159
Battery	IC	Midsize PC/Perf PC	$5,884	$5,683	$5,683	$5,522	$5,522	$5,522	$5,522	$5,522	$3,478
Battery	IC	Large PC/Perf PC	$6,807	$6,574	$6,574	$6,387	$6,387	$6,387	$6,387	$6,387	$4,023
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$318	$317	$316	$315	$314	$313	$313	$312	$201
Non-battery	IC	Midsize PC/Perf PC	$576	$574	$573	$571	$570	$568	$567	$566	$365
Non-battery	IC	Large PC/Perf PC	$965	$962	$959	$957	$954	$952	$950	$949	$611
Charger	IC	All	$125	$120	$120	$116	$116	$116	$116	$116	$69
Charger Labor	IC	All	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$17,766	$15,099	$15,099	$12,965	$12,965	$12,965	$12,965	$12,965	$9,519
Battery	TC	Midsize PC/Perf PC	$19,563	$16,626	$16,626	$14,276	$14,276	$14,276	$14,276	$14,276	$10,482
Battery	TC	Large PC/Perf PC	$22,630	$19,232	$19,232	$16,514	$16,514	$16,514	$16,514	$16,514	$12,125
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$730	$717	$704	$692	$680	$668	$660	$653	$535
Non-battery	TC	Midsize PC/Perf PC	$1,324	$1,300	$1,277	$1,254	$1,232	$1,211	$1,197	$1,183	$969
Non-battery	TC	Large PC/Perf PC	$2,218	$2,178	$2,139	$2,101	$2,064	$2,028	$2,005	$1,982	$1,623
Charger	TC	All	$516	$432	$432	$366	$366	$366	$366	$366	$269
Charger Labor	TC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Table V-86

NHTSA Costs for EV150 Applied in Volpe Model with No Mass Reduction (2009$)

Tech.	Cost type	NHTSA Vehicle Class	2017	2018	2019	2020	2021	2022	2023	2024	2025
Battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$16,195	$12,956	$12,956	$10,365	$10,365	$10,365	$10,365	$10,365	$8,292
Battery		Midsize PC/Perf PC	$17,944	$14,355	$14,355	$11,484	$11,484	$11,484	$11,484	$11,484	$9,187
Battery	DMC	Large PC/Perf PC	$21,463	$17,170	$17,170	$13,736	$13,736	$13,736	$13,736	$13,736	$10,989
Non-battery	DMC	Subcompact PC/Perf PC Compact PC/Perf PC	$415	$403	$391	$379	$368	$357	$350	$343	$336
Non-battery	DMC	Midsize PC/Perf PC	$746	$723	$702	$681	$660	$640	$628	$615	$603
Non-battery	DMC	Large PC/Perf PC	$1,254	$1,216	$1,180	$1,144	$1,110	$1,077	$1,055	$1,034	$1,014
Charger	DMC	All	$391	$313	$313	$250	$250	$250	$250	$250	$200
Charger Labor	DMC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$6,967	$6,728	$6,728	$6,538	$6,538	$6,538	$6,538	$6,538	$4,118
Battery	IC	Midsize PC/Perf PC	$7,719	$7,455	$7,455	$7,243	$7,243	$7,243	$7,243	$7,243	$4,562
Battery	IC	Large PC/Perf PC	$9,233	$8,917	$8,917	$8,664	$8,664	$8,664	$8,664	$8,664	$5,457
Non-battery	IC	Subcompact PC/Perf PC Compact PC/Perf PC	$320	$319	$318	$317	$316	$315	$315	$314	$202
Non-battery	IC	Midsize PC/Perf PC	$574	$573	$571	$570	$568	$567	$566	$565	$363
Non-battery	IC	Large PC/Perf PC	$966	$963	$960	$958	$955	$953	$951	$949	$611
Charger	IC	All	$125	$120	$120	$116	$116	$116	$116	$116	$69
Charger Labor	IC	All	$0	$0	$0	$0	$0	$0	$0	$0	$0
Battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$23,162	$19,684	$19,684	$16,902	$16,902	$16,902	$16,902	$16,902	$12,410
Battery	TC	Midsize PC/Perf PC	$25,663	$21,810	$21,810	$18,727	$18,727	$18,727	$18,727	$18,727	$13,750
Battery	TC	Large PC/Perf PC	$30,696	$26,087	$26,087	$22,400	$22,400	$22,400	$22,400	$22,400	$16,446
Non-battery	TC	Subcompact PC/Perf PC Compact PC/Perf PC	$735	$722	$709	$696	$684	$672	$664	$657	$538
Non-battery	TC	Midsize PC/Perf PC	$1,320	$1,296	$1,273	$1,250	$1,228	$1,207	$1,193	$1,180	$966
Non-battery	TC	Large PC/Perf PC	$2,220	$2,179	$2,140	$2,102	$2,065	$2,029	$2,006	$1,984	$1,625
Charger	TC	All	$516	$432	$432	$366	$366	$366	$366	$366	$269
Charger Labor	TC	All	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

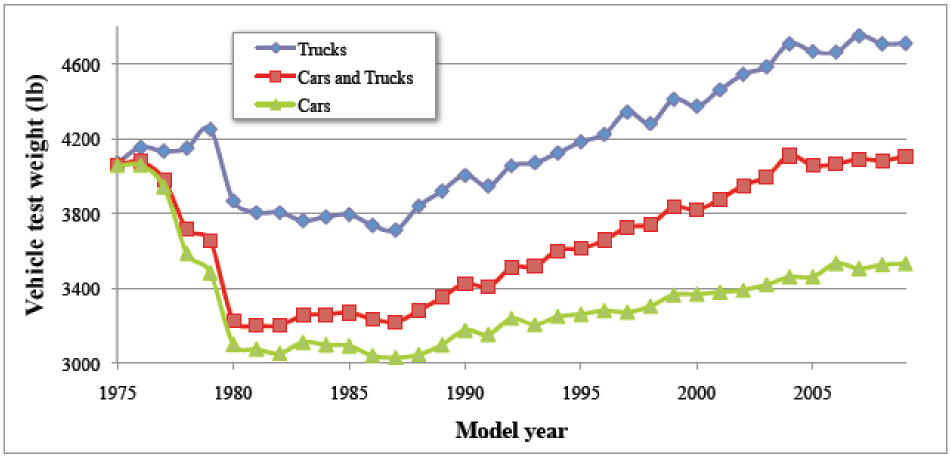
Vehicle Technologies

Mass Reduction

Over the past 20 years, there has been a generally increasing trend in the weight of the light duty vehicle fleet as shown in

Figure V-21 from EPA's Fuel Economy Trends Report.[216] There have been a number of factors contributing to this weight increase including manufacturers choosing to build and consumers choosing to 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 (air conditioning), luxury features (infotainment systems, power locks and windows), etc.
This increased weight in the fleet has been partially enabled by the increased efficiency of vehicles, especially in engines and transmissions. The impressive improvements in efficiency during this period have allowed for greater weight carrying and volume capacity (and towing), safety, consumer features and vehicle refinement, as well as greater acceleration performance.

Figure V-21 Light Duty Fleet Weight characteristics 1975-2010



Since 1987, on average, the overall fleet has become heavier and faster while fuel economy has not shown marked or consistent increases. A calculation by researchers at the University of California Davis[217] shows the combined impact of the fleet getting heavier while having approximately stable fuel economy from 1987 to 2009 in ton-mpg terms. The improvement in the fleet's technical efficiency is illustrated below in

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[216] "Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2008", EPA420-R-08-015, U.S. Environmental Protection Agency Office of Transportation and Air Quality, September 2008

[217] Lutsey, Nicholas P. (2010) Review of Technical Literature and Trends Related to Automobile Mass-Reduction Technology. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-10-10. Docket No. NHTSA-2010-0131 or Available at http://pubs.its.ucdavis.edu/publication_detail.php?id=1390 (last accessed November 14, 2011)

Figure V-21. During the same period, there are many improvements in vehicle performance, such as faster vehicle acceleration shown in Figure V-22 and reduced fatality in the fleet as shown in Figure V-23.

Figure V-22 U.S. Light duty Fleet trends for weight, acceleration, fuel economy and weight-adjusted fuel economy for model years 1975-2009

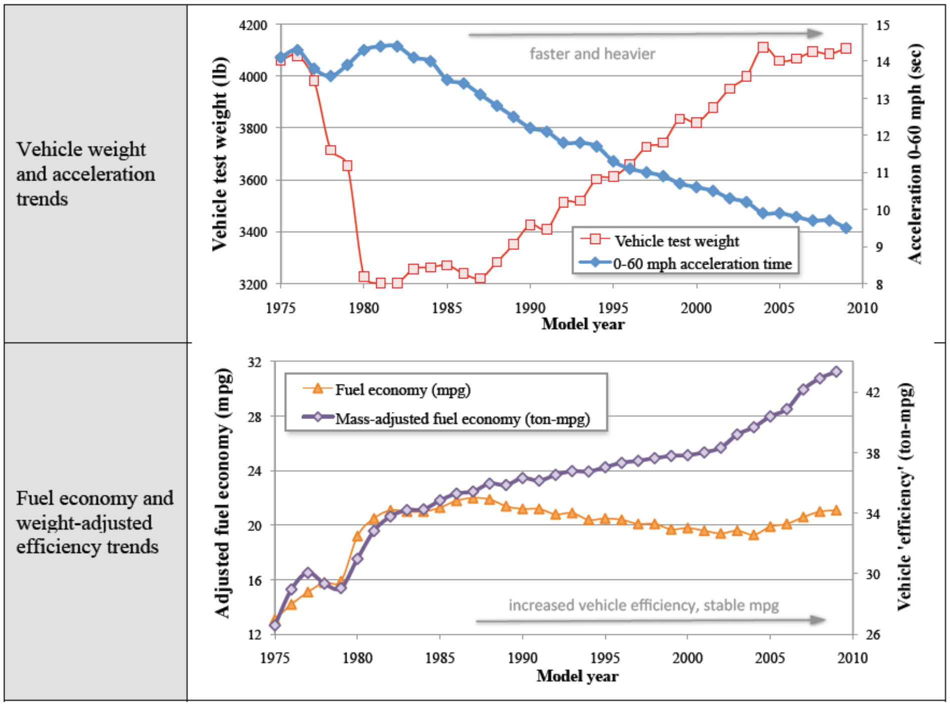
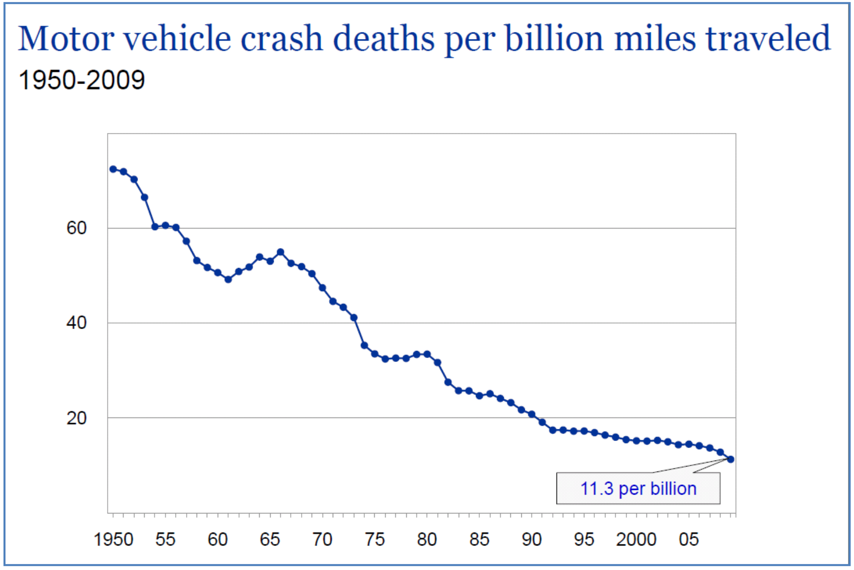


Figure V-23 U.S. Vehicle Fatality for the past 60 years[218]



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[218] Adrian Lund, IIHS, "The Relative Safety of Large and Small Passenger Vehicles", February 25, 2011. Docket No. NHTSA-2010-0131 or Available at http://www.nhtsa.gov/staticfiles/rulemaking/pdf/MSS/MSSworkshop-Lund.pdf (last accessed November 14, 2011)

Reducing a vehicle's mass, or "down-weighting" the vehicle, decreases fuel consumption by reducing the energy demand needed to overcome forces resisting motion. Mass reduction can be also achieved by vehicle "downsizing" where a vehicle is physically reduced in size by reducing exterior dimensions, such as shifting from a midsize vehicle to a compact vehicle. Both vehicle down-weighting and vehicle downsizing can yield lower GHG emission and reduce fuel consumption. But vehicle downsizing is dependent on the consumer choices which are influenced by many factors, such as the consumer's utility needs, fuel prices, economic conditions, etc. [219] In this NPRM analysis, the agencies are not analyzing downsizing since we are assuming that the attribute based standards will not exert any regulatory pressure for manufacturers to change the size of vehicles in order to come into compliance with the proposed standards (as described in Section II.F of the Preamble and Chapter 2 of the joint TSD). Instead we are assuming that manufacturers will favor down-weighting of a vehicle through material substitution, design optimization and adopting other advance manufacturing technologies while not compromising a vehicle's attributes and functionalities, such as occupant or cargo space, vehicle safety, comfort, acceleration performance, etc. While keeping everything else constant, the lighter a vehicle is, the less fuel is needed to drive the vehicle over a driving cycle. Researchers and industry have used a rule of thumb, based on testing and simulation, that 10 percent reduction in vehicle mass can be expected to generate a 6 to 7 percent increase in fuel economy if the vehicle powertrain and other components are also downsized accordingly.[220] A recent 2010 Ricardo study, funded by EPA, updated this range to 5 to 8 percent increase in fuel economy.

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, boosted and downsized gasoline, diesel, 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. Often times the term "glider" is used to include all of the vehicle parts except for the powertrain of the vehicle.

Figure V-24illustrates a typical vehicle system mass breakdown.[221] Normally the non-powertrain systems account for 75 percent of vehicle weight and this is what the agencies are focusing on for this discussion.

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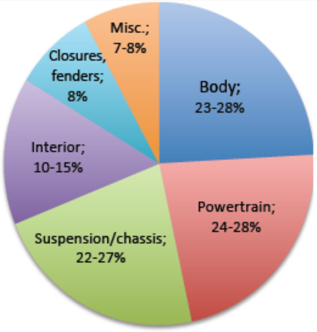
[219] Vehicle mass reduction is very different that vehicle "down-sizing". Vehicle downsizing can confuse or confound the analysis of mass-reduction technology trends; however these are distinctly different factors.

[220] National Academy of Science "Assessment of Fuel Economy Technologies for Light-Duty Vehicles." June 2010. Available at http://www.nap.edu/catalog.php?record_id=12924 (last accessed November 11, 2011)

[221] Lutsey, Nicholas P. (2010) Review of Technical Literature and Trends Related to Automobile Mass-Reduction Technology. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-10-10. Docket No. NHTSA-2010-0131 or Available at http://pubs.its.ucdavis.edu/publication_detail.php?id=1390 (last accessed November 14, 2011)

Figure V-24 Vehicle system mass approximation

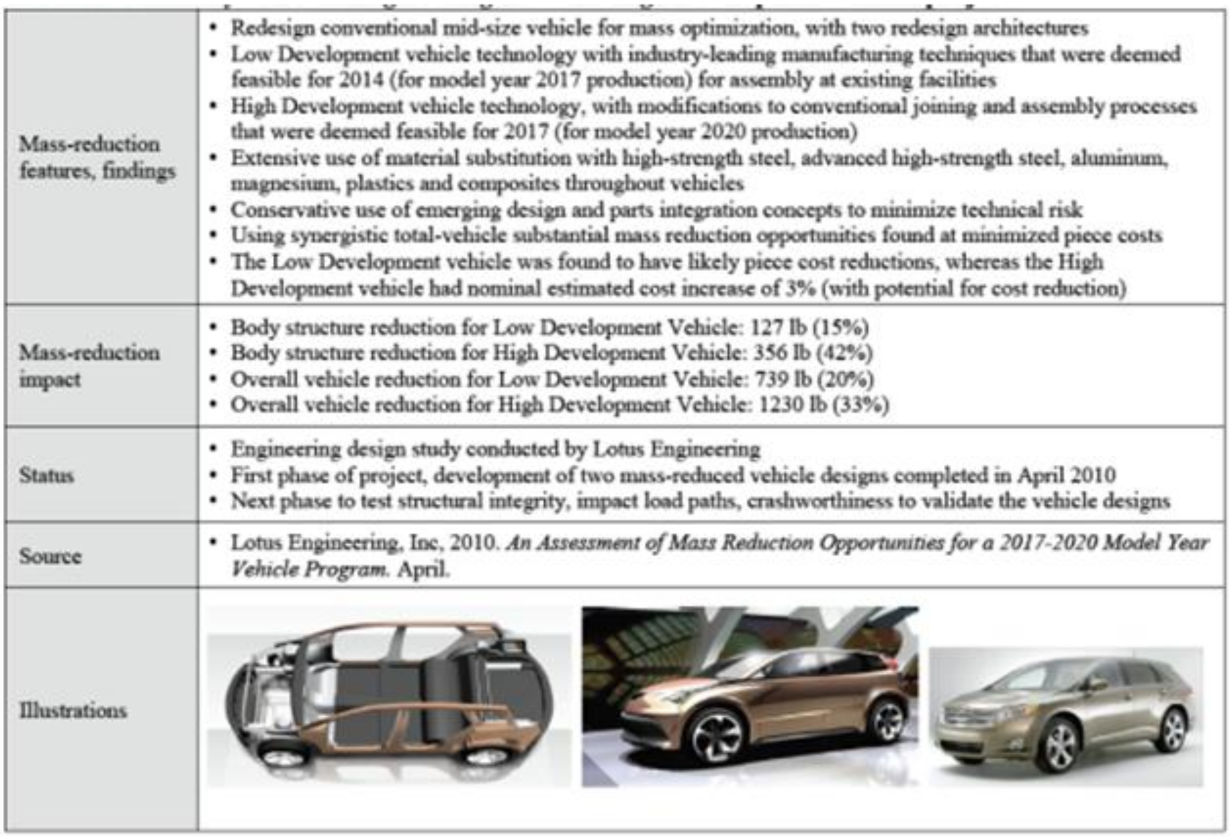
Approximate vehicle mass breakdown[a]	System	Major components in system
 Misc.; 7-8% Closures, fenders; 8% Body; 23-28% Interior; 10-15% Powertrain; 24-28% Suspension/chassis; 22-27%	Body-in-white	Passenger compartment frame, cross and side beams, roof structure, front-end structure, underbody floor 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

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. Manufacturers generally tend to undertake larger amounts of mass reduction systematically and more broadly across all vehicle systems when redesigning a vehicle. For example, if a manufacturer applies a smaller, lighter engine with lower torque-output to a vehicle, this can allow the use of a smaller, lighter-weight transmission and drive line components, because those components need not be as heavy and robust to support equivalent performance in the redesigned vehicle with a smaller engine. 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. When redesigning vehicles, 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, taking into consideration of all secondary mass savings, is the most effective way for OEMs to achieve large amount 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 vehicles for much greater potential mass reduction.

Figure **V-25** illustrates an example of this approach and how significant mass reduction opportunities can be achieved when a complete vehicle redesign is undertaken.

Figure V-25
Summary of Lotus Engineering Low and High Development Vehicle Projects



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: 127 lb (15%) • Body structure reduction for High Development Vehicle: 356 lb (42%) • Overall vehicle reduction for Low Development Vehicle: 739 lb (20%) • Overall vehicle reduction for High Development Vehicle: 1230 lb (33%)
Status	• Engineering design study conducted by Lotus Engineering • First phase of project, development of two mass-reduced vehicle designs completed in April 2010 • Next phase to test structural integrity, impact load paths, crashworthiness to validate the vehicle designs
Source	• Lotus Engineering, Inc, 2010. *An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program.* April.
Illustrations	

It is appropriate for both manufacturers and the agencies to consider mass reduction in terms of "percent by which the redesigned vehicle is lighter than the previous version," recognizing that that percent 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 having made the primary mass reductions).

As in the MYs 2012-2016 rulemaking analysis, the agencies are assuming that up to 1.25 kg of 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.[222] We note that this estimate 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 50% to 125% depending on what is assumed, such as which components or systems primary mass reduction is applied to, and whether the powertrain is available for downsizing. [223, 224,225] The ability to reduce mass is affected by the consideration

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[222] Reddy, "Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients," Auto-Steel Partnership Report, May 2007. Available at http://www.a-sp.org/database/custom/Mass%20Compounding%20-%20Final%20Report.pdf (last accessed Aug. 17, 2011).

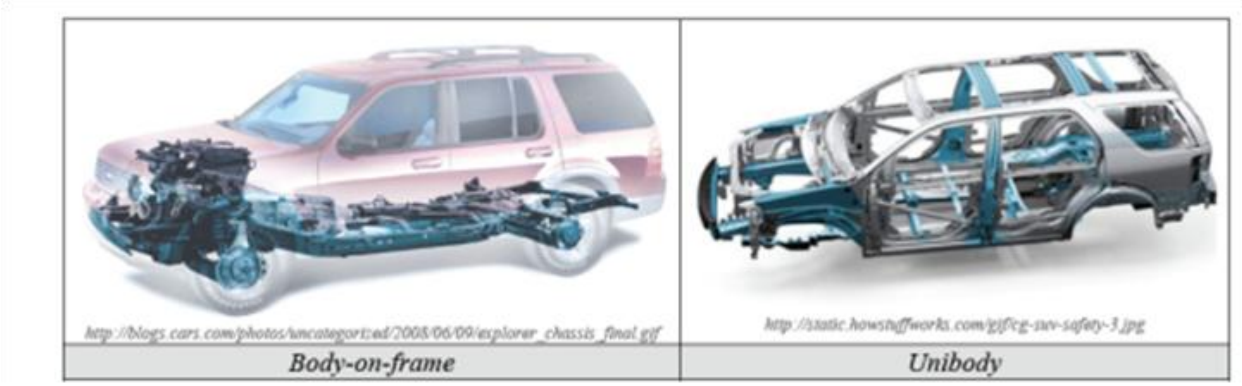
[223] Malen and Reddy, "Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients," Auto-Steel Partnership Report, May 2007. Available at http://www.a-sp.org/database/custom/Mass%20Compounding%20-%20Final%20Report.pdf (last accessed Aug. 17, 2011).

of component sharing among different vehicles to achieve production economies of scale that affect cost and that also affect 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 if compounding effects have been considered and how.

Mass reduction can occur through a variety of techniques available to manufacturers. As summarized by NAS in its 2011 report, there are two key strategies for reducing vehicle mass, changing the design to use less material or substituting light-weighting materials for heavier materials while maintaining performance (safety and stiffness).[226] The first approach is to use less material comparing to the baseline component by optimizing the design and structure of the component, system or vehicle structure. For an example, a "body on frame" vehicle can be redesigned with a lighter "unibody" construction by eliminating the number of components and reducing the weight of the overall body structure, resulting in significant mass reduction and related cost reduction. The unibody design dominates the passenger car segment and has an increasing penetration into what used to be body-on-frame vehicles, such as SUVs. This technique was used in the 2011 Ford Explorer redesign in addition to extensive use of high strength steels[227].

Figure V-26 depicts body-on-frame and unibody designs for two sport utility vehicles.

Figure V-26 Illustration of Body-on-Frame (BoF) and Unibody vehicle construction



http://blogs.cars.com/photos/uncategorized/2008/06/09/explorer_chassis_final.gif

http://static.howstuffworks.com/gif/cg-suv-safety-3.jpg

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[224] 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. Available at http://aluminumintransportation.org/downloads/IBIS-Powertrain-Study.pdf (last accessed Aug. 17, 2011).

[225] http://msl.mit.edu/students/msl_theses/Bjelkengren_C-thesis.pdf

[226] NAS, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles", pg 100, 2011

[227] Ford Sustainability Report 2010/11, http://corporate.ford.com/microsites/sustainability-report-2010-11/issues-climate-plan-economy (last accessed Aug. 26, 2011)

Manufactures can also continue to utilize Computer Aided Engineering (CAE) tools to further reduce inefficiencies in vehicle design. For example, the Future Steel Vehicle (FSV) project[228] sponsored by the 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 vehicle body structure with a unibody design. Designs similar to some used in the FSV project have been applied in production vehicles, such as the B-pillar of new Ford Focus.[229] An example of this process is shown in the Future Steel Vehicle project in Figure V-27.

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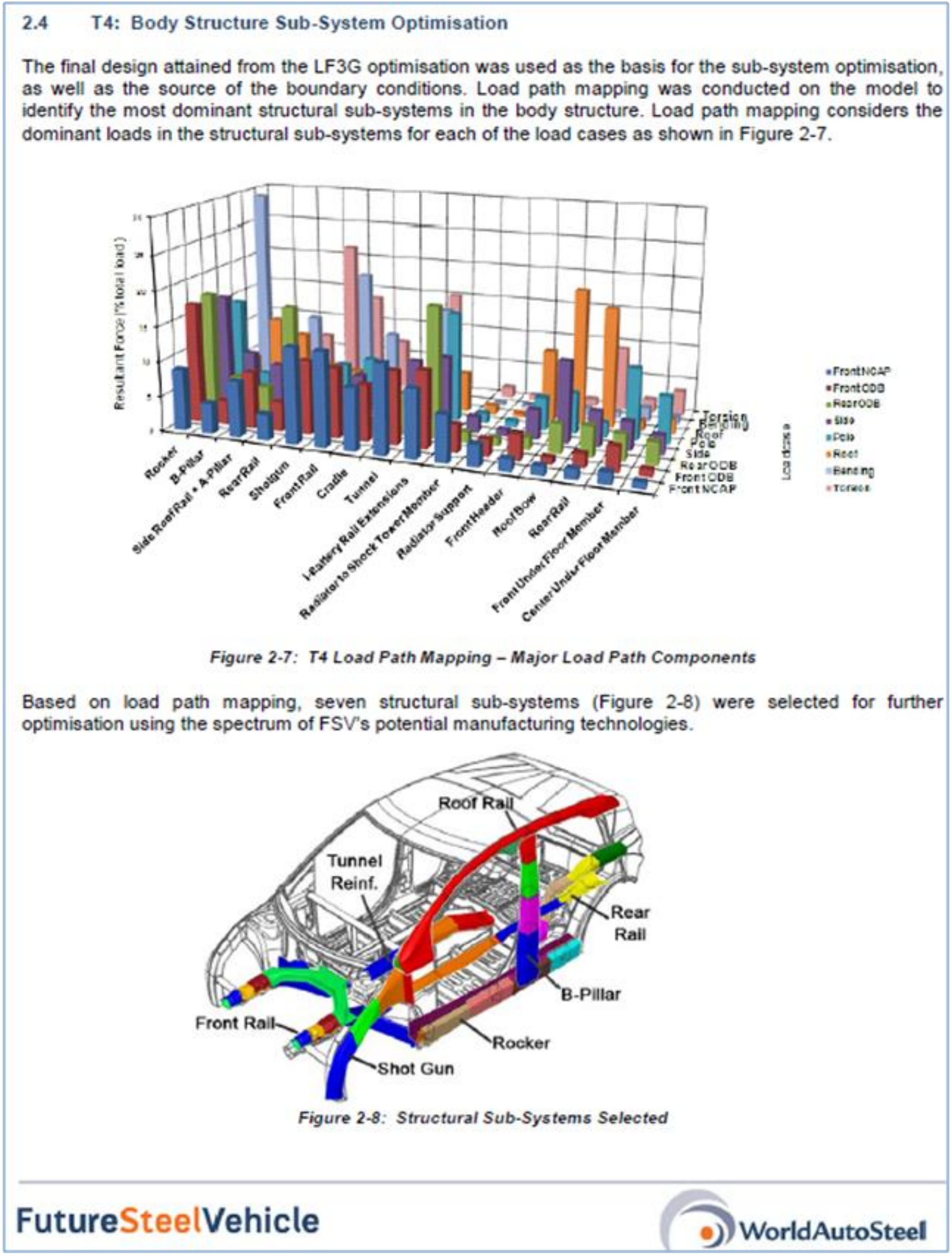
[228] "Future Steel Vehicle: Overview Report", April 2011, http://www.worldautosteel.org/FSV_OverviewReport_Phase2_FINAL_20110430.pdf (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131

[229] "Focus B-pillar 'tailor rolled' to 8 different thicknesses", SAE World Congress, Automotive Engineering Online, February, 2010. Available at http://www.sae.org/mags/AEI/7695 (last accessed November 14, 2011)

Figure V-27 Example of vehicle body load path mapping for mass optimization



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

Vehicle manufacturers have long used these continually-improving CAE tools to optimize vehicle designs. But because any design must maintain component and system functionality, there are practical limitations to the amount of additional design improvement and mass reduction that can be achieved through optimization. Additionally, ultimate optimization of vehicle design for mass reduction may be limited by OEMs' typical use of a common platform for multiple vehicle models. While optimization may concentrate of 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. 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, it is inherent that some level of mass inefficiency will exist on many or all of the vehicles that share a platform. The agencies seek comment and information 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. 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. Additionally, while synergies in mass reduction certainly exist, and while certain technologies (*e.g.*, parts consolidation and molding of advanced composites) can enable one another, others (*e.g.*, laser welding and magnesium casting) may be incompatible.

The second key strategy to reduce mass of an assembly or component involves the substitution of lower density and/or higher strength materials. Table V-87 shows material usage typical to high-volume vehicles. Material substitution includes replacing materials, such as mild steel, with advanced and regular higher-strength steels, aluminum, magnesium and/or composite materials. The substitution of advanced high strength steel (AHSS) can reduce the mass of a steel part because AHSS has higher strength than mild steel and therefore less material is needed in strength-critical components despite the fact that its density is not significantly different from mild steel. Some manufacturers are considering even more advanced materials for many applications, but the advanced microstructure and limited industry experience with some materials 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 rulemaking. Material substitution also tends to be quite manufacturer and situation specific in practice; some materials work better than others for some vehicle components and a manufacturer may invest more heavily in adjusting its manufacturing to a particular type of advanced material and complicate 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 noise, vibration and harshness (NVH).

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 replacing nonstructural vehicle components, plastics have continued to make in-roads in bumper systems and in composite beam applications and a number of studies have found potential to supplant structural beams and frame component. Additionally included in this general category are the more costly composites, like glass fiber and carbon fiber reinforced polymers. These materials, to date, are used primarily in limited applications in low-production-volume vehicles.

Table V-87 Distribution of Material in Typical Contemporary Vehicles (e.g. Toyota Camry and Chevrolet Malibu)[230]

Material	**Comments**	**Approximate Content in Cars Today, by Weight (%)**
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

If vehicle mass is reduced sufficiently, 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 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) with similar powertrain durability.

All manufacturers are using some or all of these methods to some extent 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 content, some of which is feature 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

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[230] NAS, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," pg 100, 2011. Available at http://www.nap.edu/catalog.php?record_id=12924 or Docket No. NHTSA-2010-0131

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 for the use of all the mass reduction methods described above (and in the literature search portion of the above cost discussion). This represents the significant complexity of mass reduction technologies for improving fuel economy and reducing CO_2 emissions.

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 other constraints, is nearly unbounded. However, the feasible amount of mass reduction is affected by other considerations. Cost effectiveness is one of those constraints and is discussed in the cost section, above. In the analysis for the MYs 2012-2016 rulemaking, NHTSA assumed different amounts of mass reduction (defined as net reduction of a percentage of total vehicle mass) were feasible for different vehicle subclasses in different model years. In addition, it was assumed that more mass was taken out at a redesign and/or later in the rulemaking timeframe than at a refresh and/or earlier in the rulemaking timeframe. More specifically, NHTSA assumed that mass could be reduced 1.5 percent at any refresh or redesign, and that mass could be reduced an additional incremental 3.5-8.5 percent (3.5 for smaller vehicles, 8.5 for the largest vehicles) at redesigns after MY 2014 to provide lead time for these larger mass reduction amounts. The amount (percentage) of mass reduction that the NHTSA used in the analysis generally aligned with information that the agencies received, during the MY 2012-2016 rulemaking, from manufacturers related to their plans to reduce mass of larger vehicles more than smaller vehicles in the 2012-2016 timeframe. Based on the NHTSA's analysis, it was estimated that mass reduction in response to the MY 2012-2016 program would achieve a safety-neutral result.
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 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 in Table V-90 and sections where future studies are discussed later on in this section.

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 CO2 emission standards. Estimates from Ducker Worldwide indicate that the automobile industry will see an annual increase in AHSS of about 10% through 2020.[231] Ford has stated that it intends to reduce the weight of its vehicles by 250-750 lb per model from 2011 to 2020.[232] For context, the midpoint of that range of reductions

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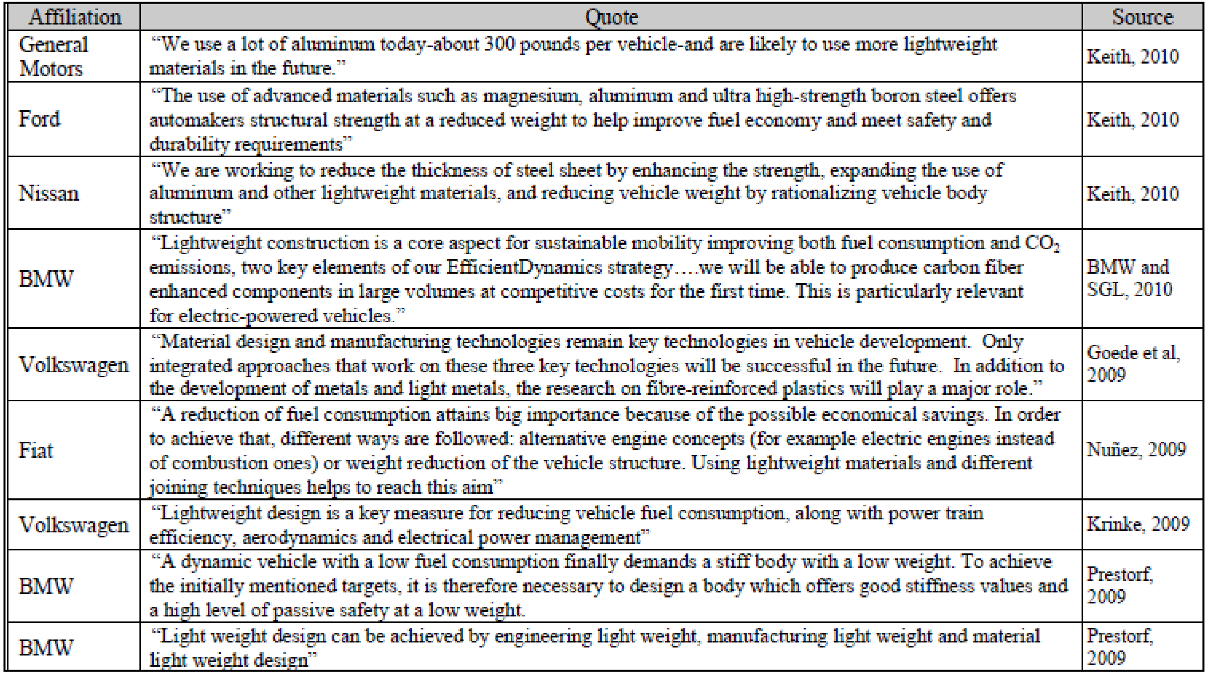
[231] American Iron and Steel Institute (AISI), 2009. "New Study Finds Increased Use of Advanced High-Strength Steels Helps Decrease Overall Vehicle Weight." http://www.prnewswire.com/news-releases/new-study-finds-increased-use-of-advanced-high-strength-steels-helps-decrease-overall-vehicle-weight-61851732.html (last accessed November 14, 2011)

[232] Ford, 2010. "The 5.0 Liter is Back: 2011 Ford Mustang GT Leads Class with 412 HP, Fuel Efficiency, Chassis Dynamics." http://media.ford.com/article_display.cfm?article_id=31645. (last access November 14, 2011)

would correspond to a 12% reduction from the current Ford new light duty vehicle sales fleet. Similarly, Nissan has a target of a 15% mass reduction per vehicle by 2015.[233] This reduction would represent over a 500-lb reduction from their 2008 light duty vehicle average. Mazda's has released a statement about achieving a 220-lb reduction per vehicle by 2016.[234] This is equivalent to about a 6% reduction for the company's current fleet. Toyota stated that it could end up reducing the mass of the Corolla and mid-size models by 30% and 10%, respectively, in the 2015 timeframe. The low end of those targets, 10%, is equivalent to 350 lb per Toyota vehicle in 2008. Land Rover remains committed to a goal of reducing curb weights of its SUV's by as much as 500 kilograms over the next 10 years.[235] Several reports are summarized in the University of California study as shown in Table V-88.[236]

Table V-88 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"	Keith, 2010
Nissan	"We are working to reduce the thickness of steel sheet by enhancing the strength, expanding the use of aluminum and other lightweight materials, and reducing vehicle weight by rationalizing vehicle body structure"	Keith, 2010
BMW	"Lightweight construction is a core aspect for sustainable mobility improving both fuel consumption and CO_2 emissions, two key elements of our EfficientDynamics strategy….we will be able to produce carbon fiber enhanced components in large volumes at competitive costs for the first time. This is particularly relevant for electric-powered vehicles."	BMW and SGL, 2010
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 helps to reach this aim"	Nuñez, 2009
Volkswagen	"Lightweight design is a key measure for reducing vehicle fuel consumption, along with power train 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, manufacturing light weight and material light weight design"	Prestorf, 2009

The agencies also 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

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[233] Keith, D., 2010. "HSS, AHSS and aluminum jockey for position in the race to cut auto curb weight." American Metal Market Monthly.
[234] U.S. Environmental Protection Agency (U.S. EPA), 2009b. Draft Regulatory Impact Analysis: Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards. September. EPA-420-D-09-003.
[235] 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
[236] "Review of technical literature and trends related to automobile mass-reduction technology", May 2010 http://www.arb.ca.gov/msprog/levprog/leviii/meetings/051810/2010_ucd-its-rr-10-10.pdf

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 NPRM preamble. In the CAFE and OMEGA analyses, the agencies considered several levels of mass reduction to all of the models in each subclass as shown in

Table V-89.

Based on the many aspects of mass reduction (*i.e.*, feasibility, cost and safety), for 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 further, we remain alert to safety considerations and seek to ensure that any CAFE and CO_2 standards can be achieved in a safety-neutral manner.

In the CAFE model, NHTSA applied the amounts of mass reduction shown in

Table V-89, which enabled us to achieve overall fleet fatality estimates of close to zero.

Table V-89 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%	2.0%	1.5%	1.5%	1.5%	1.5%
MR2	0.0%	0.0%	5.0%	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 V-89, however, 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 assumes 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 as stated in Chapter 3 of the draft joint TSD. This assumption, which we believe accurately, reflects real-world HEV, PHEV and EV construction, as an example, for a subcompact PHEV with 20 mile range operating on electricity, because of the additional weight of the electrification system, the agencies assume that to achieve no change in total vehicle mass, it would be necessary to reduce the mass of the glider (the vehicle without the powertrain), by 6 percent. The mass reductions for HEV/PHEV/EVs can be found above in this document and section 3.4.3.9 of the draft joint TSD.

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.[237]

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

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[237] 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.

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 s 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. 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 decompounding can also confound comparisons.[238] 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.[239]

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 pound of mass reduction as a function of total percentage of mass reduction. There are many significant challenges that make

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[238] 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.

[239] We also note that the cost of mass reduction in the Volpe 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 Volpe model strives to be realistic in the aggregate while recognizing that the figures proposed for any specific model may be debatable.

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. The agencies initially considered using the flat rate cost estimate that was used for the last rulemaking, $1.32/lb, but as discussed above, there are appropriate reasons to consider a variable cost curve. The agencies then considered the cost estimates from the TAR, but have noted that there is more data available at present that could potentially be useful in informing our estimates. Nonetheless, coalescing these disparate datasets into a single curve has limitations since the various studies are not directly comparable.

With these challenges in mind, and because the agencies have not finished the significant mass reduction studies targeted for the CAFE and GHG rulemaking (described below), the agencies examined all the studies in Table V-90 including information supplied by manufacturers (during meetings held subsequent to the TAR) when deciding the mass reduction cost estimate used for this NPRM.[240] 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 2010 NAS study speaks to this point when it states on page 7-1 that "The 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 the whole fleet.

Table V-90 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,

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[240] 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.

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 V-90 is inclusive of all of the information reviewed by the agencies, for the reasons described above the technical staff for the two agencies applied various different approaches in evaluating the information. The linear mass-cost relationship developed for this proposal and presented below is the consensus assessment from the two agencies of the appropriate mass cost for this proposal.

Table V-90 Mass Reduction Studies Considered for Estimating Mass Reduction Cost for this NPRM

Studies	Cost Year	Cost Information from Studies									
		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

Table V-88(… Continued) Mass Reduction Studies Considered for Estimating Mass Reduction Cost for this NPRM

Studies	Cost Year	Cost Information from Studies									
		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 this proposal is defined by the following equation:

Mass Reduction Direct Manufacturing Cost (\$/lb) = 4.32 x Percentage of Mass Reduction

For example, this results in an estimated \$173 cost increase for a 10% mass reduction of a 4,000lb vehicle (or \$0.43/lb), and a \$390 cost increase for 15% reduction on the same vehicle (or \$0.65/lb).

Because of the wide variation in data used to select this estimated cost curve, the agencies have also conducted cost sensitivity studies in their respective RIAs using values of +/-40%. The wide variability in the applicability and rigor of the studies also provides justification for continued research in this field, such as the agency studies discussed below. The assessment of the current studies highlights the importance of these agency studies, as they are expected to be amongst the most comprehensive ever conducted in the literature, and to be more informative than other studies for estimating the cost of mass reduction for purposes of rulemaking.
The agencies consider this DMC to be applicable to the 2017MY and consider mass reduction technology to be on the flat portion of the learning curve in the 2017-2025MY 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 seek detailed comment 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. For example, the agencies seek 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. If commenters wish to submit additional studies for the agencies' consideration, it would assist the agencies if commenters could address how the studies also contribute to the agencies' understanding of the issues enumerated above. The agencies also note that we expect to refine our estimate of both the amount and the cost of mass reduction between the NPRM and the final rule based on the ongoing work described below.

How effective do the agencies estimate that mass reduction will be?

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 2010 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 NPRM, 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 (Contract No. EP-C-11-007). 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 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 which avoids 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 proposal 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 will focus their research efforts and undertake further study. Some studies focus on the potential safety effects of mass reduction through fleet wide analyses, and thus help to inform the agencies with regard to how much mass reduction might appropriately be deemed feasible in the rulemaking timeframe, while others focus on the cost and feasibility of reducing mass in specific vehicles. The results of all of these studies are currently expected to be available for the final rule, and should contribute significantly to informing the agencies' estimates of the costs and feasible amounts of mass reduction to be included in that analysis. The following is an update for the status of those studies.

The agencies and independent researchers have several vehicle level projects to determine the maximum potential for mass reduction in the MY 2017-2021 timeframe by using advanced materials and improved designs while continuing to meeting safety regulations and maintaining functionality of vehicles, and one study that will investigate the effects of resultant designs on fleet safety:

- NHTSA has awarded a contract to Electricore, with EDAG and George Washington University (GWU) as subcontractors, to study the maximum feasible amount mass reduction for a mid-size car – specifically, a Honda Accord. The study tears down a MY 2011 Honda Accord, studies each component and sub-system, and then redesigns each component and sub-system trying to maximize the amount of mass reduction with technologies that are considered feasible for 200,000 units per year production volume during the time frame of this rulemaking. Electricore and its sub-contractors are consulting industry leaders and experts for each component and sub-system when deciding which technologies are feasible. Electricore and its sub-contractors are also building detailed CAD/CAE/powertrain models to validate vehicle safety, stiffness, NVH, durability, drivability and powertrain performance. For OEM-supplied parts, a detailed cost model is being built based on a Technical Cost Modeling (TCM) approach developed by the Massachusetts Institute of Technology (MIT) Materials Systems Laboratory's research[241] for estimating the manufacturing costs of OEM parts. The cost will be 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 are then categorized into fixed cost, such as tooling, equipment, and facilities; and variable costs such as labor, material, energy, and maintenance. These costs will be assessed through an interactive process between the product designer, manufacturing engineers and cost analysts. For OEM-purchased parts, the cost will be estimated by consultation with experienced cost analysts and Tier 1 system suppliers. This study will help to inform the agencies about the feasible amount of mass reduction and the cost associated with it. NHTSA intends to have this study completed and peer reviewed before July 2012, in time for it to play an integral role in informing the final rule.

- EPA has awarded a contract to FEV, with EDAG and Monroe & Associates, Inc. as subcontractors, to study the maximum feasible amount of mass reduction for a mid-size CUV (cross over vehicle) specifically, a Toyota Venza. The study tears down a MY 2010 vehicle, studies each component and sub-system, and then redesigns each component and sub-system trying to maximize the amount of mass reduction with technologies that are considered feasible for high volume production for a 2017 MY vehicle. FEV in coordination with EDAG is building detailed CAD/CAE/powertrain models to validate vehicle safety, stiffness, NVH, durability, drivability and powertrain performance to assess the safety of this new design. This study builds upon the low development (20% mass reduction) design in the 2010 Lotus Engineering study "An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program". This study will undergo a peer review. EPA intends to have this study completed and peer reviewed before July 2012, in time for it to play an integral role in informing the final rule.

- California Air Resources Board (CARB) has awarded a contract to Lotus Engineering, to study the maximum feasible amount mass reduction for a mid-size CUV (cross over vehicle) specifically, a Toyota Venza. The study will concentrate on the Body-in-White and closures in the high development design (40% mass reduction) in the Lotus Engineering study cited above. The study will provide an updated design with crash simulation, detailed costing and manufacturing feasibility of these two systems for a MY2020 high volume production vehicle. This study will undergo a peer review. CARB intends to have this study completed and peer reviewed before July 2012, in time for it to play an integral role in informing the final rule.

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[241] 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).

- NHTSA has contracted with GWU to build a fleet simulation model to study the impact and relationship of light-weighted vehicle design and injuries and fatalities. This study will also include an evaluation of potential countermeasures to reduce any safety concerns associated with lightweight vehicles. NHTSA will include 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). This study will help to inform the agencies about the possible safety implications for light-weighted vehicle designs and the appropriate counter-measures,[242] if applicable, for these designs, as well as the feasible amounts of mass reduction. All of these analyses are expected to be finished and peer-reviewed before July 2012, in time to inform the final rule.

Safety considerations in establishing CAFE/GHG standards along with discussion of NHTSA's February 25, 2011, mass-size-safety workshop at DOT headquarter, can be found in Section II.G of the preamble for this proposal. NHTSA plans to host additional workshops when the studies have reached a sufficient level of completion, to share the results with the public and seek public comments.

Low Drag Brake (LDB)

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 high as 1 percent. NHTSA and EPA have slightly revised the effectiveness down to 0.8 percent based on the 2011 Ricardo study and the updated lumped parameter model.

In the MYs 2012-2016 final rule, the agencies estimated the DMC at $57 (2007$). This DMC becomes $58 (updated to 2009$) for this analysis. The agencies consider low drag brake technology to be off the learning curve (*i.e.*, fully learned out, so that the DMC does not change year-over-year) and have applied a low complexity ICM of 1.24 through 2018, switching to a long-term ICM of 1.19 thereafter. The resultant costs are shown in

Table V-91.

Table V-91 Costs for Low Drag Brakes (2009$)

Cost type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$58	$58	$58	$58	$58	$58	$58	$58	$58
IC	$14	$14	$11	$11	$11	$11	$11	$11	$11
TC	$73	$73	$70	$70	$70	$70	$70	$70	$70

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

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[242] Countermeasures could potentially involve improved front end structure, knee bags, seat ramps, buckle pretensioners, and others.

Low Rolling Resistance Tires – Level 1and Level 2 (ROLL1 and ROLL2)

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. 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 proposal, the agencies are considering two "levels" of lower rolling resistance tires. The first level ("ROLL1") 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 MYs 2012-2016 final rule. Based on the 2011 Ricardo study, the agencies are now using 1.9 percent for all classes. ROLL1 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 ("ROLL2") is defined as a 20 percent reduction in rolling resistance from a base tire, yielding an estimated 3.9 percent effectiveness. In the CAFE model this results in a 2.0 percent incremental effectiveness increase form ROLL1. ROLL2 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 could not be fully met with the ROLL2 designs in the MYs 2017-2025 timeframe. For this reason the Volpe 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 MYs 2012-2016 final rule, the agencies estimated the incremental DMC as $5 (2007$) per vehicle. This included costs associated with five tires per vehicle, four primary and one spare with no learning applied due to the commodity based nature of this technology. Looking forward from 2016, the agencies continue to apply this same estimated DMC, as adjusted for 2009 dollars.[243] The agencies consider ROLL1 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 a long-term low complexity ICM of 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

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[243] 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 $5.31 (2009$). We show $5 for presentation simplicity.

suppliers were generally optimistic about the ability of tire rolling resistance to improve 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 ROLL2 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 systems calibration and verification.

ROLL2 technology does not yet exist in the marketplace, making cost estimation challenging without disclosing potentially confidential business information. To develop a transparent cost estimate, the agencies relied on ROLL1 history, costs, market implementation, and information provided by the 2010 NAS report. The agencies assumed low rolling resistance technology ("ROLL1") 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 ROLL2 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 ROLL2 at $10 (2009$) per tire, or $40 ($2009) 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 ROLL2 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.[244] The agencies consider this estimated cost for ROLL2 to be applicable in MY 2021. Further, the agencies consider ROLL2 technology to be on the steep portion of the learning curve where costs would reduce quickly in a relative short amount of time. The agencies have applied a low complexity ICM of 1.24 through 2024, and switching to a long-term ICM of 1.19 thereafter. The ICM timing for ROLL2 is different from that for ROLL1 because ROLL2 is brand-new for this rulemaking and is not yet being implemented in the fleet. The resultant costs are shown in Table V-92. Note that both ROLL1 and ROLL2 are incremental to the baseline system, so ROLL2 is not incremental to ROLL1.

Table V-92 Costs for Lower Rolling Resistance Tires Levels 1 & 2 (2009$)

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

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[244] "The Disappearing Spare Tire" Edmunds.com, May 11, 2011; http://www.edmunds.com/car-buying/the-disappearing-spare-tire.html (last accessed 9/6/2011)

DMC	Level 2	$63	$63	$50	$50	$40	$39	$38	$37	$35
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	$6	$6	$6	$6	$6	$6	$6	$6	$6
TC	Level 2	$72	$72	$60	$60	$50	$48	$47	$46	$43

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 proposed standards cover such a long timeframe, the agencies also considered introducing a third level of rolling resistance reduction ("ROLL3"), defined as a 30 percent reduction in rolling resistance. The agencies evaluated the potential of ROLL3 entering the marketplace during this proposed 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.[245] 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 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 ROLL2 by 2025. Therefore, the agencies decided not to incorporate ROLL3 at this time.

NHTSA seeks comment, however, 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. We seek 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, we appreciate any cost information regarding the potential incorporation of ROLL3 relative to today's costs as well as during the timeframe covered by this proposal.

Front or secondary axle disconnect for four-wheel drive systems (SAX)

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. 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 axles disconnect serves two basic purposes. First, in two-wheel drive mode, it

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[245] see U.S Patent 5,227,425, Rauline to Michelin, July 13, 1993

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 MYs 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 for this analysis.

In the MYs 2012-2016 final rule, the agencies estimated the DMC at $78 (2007$) which was considered applicable to MY 2015. This DMC becomes $81 (updated to 2009$) for this analysis. 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, and then a long-term ICM of 1.19 thereafter. The resultant costs are shown in

Table V-93.

Table V-93 Costs for Secondary Axle Disconnect (2009$)

Cost type	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	$77	$75	$74	$72	$71	$69	$68	$66	$65
IC	$19	$19	$15	$15	$15	$15	$15	$15	$15
TC	$96	$94	$89	$88	$86	$85	$83	$82	$81

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Aerodynamic Drag Reduction Level 1 and Level 2(AERO1 and AERO2)

Many factors affect a vehicle's aerodynamic drag and the resulting power required to move it through the air. While these factors change with air density and the square and cube of vehicle speed, respectively, the overall drag effect is determined by the product of its frontal area and drag coefficient. Reductions in these quantities can therefore reduce fuel consumption. 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.

In the MYs 2012-2016 final rule, we estimated that a fleet average of 10 to 20 percent total aerodynamic drag reduction is attainable which equates to incremental reductions in fuel consumption 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 proposal.

For this proposal, the agencies are considering two levels of aero improvements. The first level is that discussed in MYs 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 final rule, the agencies estimated the DMC of aero-level 1 at $39 (2007$). This DMC becomes $40 (updated to 2009$) for this analysis, applicable in MY 2015. 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, and then a long-term ICM of 1.19 thereafter.

The second level of aero—level 2, which includes such body features as active grille shutters, 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 $121 (2009$). The agencies consider this cost to be applicable in MY 2015. 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, and then a long-term ICM of 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 V-94.

Table V-94 Costs for Aerodynamic Drag Improvements – Levels 1 & 2 (2009$)

Cost type	Aero Technology	Incremental to	2017	2018	2019	2020	2021	2022	2023	2024	2025
DMC	Level 1	Baseline	$38	$38	$37	$36	$35	$35	$34	$33	$33
DMC	Level 2	Aero-level 1	$115	$113	$110	$108	$106	$104	$102	$100	$98
IC	Level 1	Baseline	$10	$10	$8	$8	$8	$8	$8	$8	$8
IC	Level 2	Aero-level 1	$47	$46	$46	$46	$46	$46	$46	$46	$34
TC	Level 1	Baseline	$48	$47	$45	$44	$43	$42	$42	$41	$40
TC	Level 2	Aero-level 1	$162	$159	$157	$155	$152	$150	$148	$146	$132
TC	Level 2	Baseline	$210	$207	$201	$198	$195	$192	$190	$187	$173

DMC=Direct manufacturing cost; IC=Indirect cost; TC=Total cost

Technologies considered but not included in the final rule analysis

Lean-Burn Gasoline Direct Injection Technology

Direct injection, especially with diesel-like "spray-guided" injection systems, enables operation with excess air in a stratified or partially-stratified fuel-air mixture, as a way of reducing the amount of intake throttling. Also, with higher-pressure fuel injection systems, the fuel may be added late enough during the compression stroke so as to delay the onset of auto-ignition, even with higher engine compression ratios or with boosted intake pressure. Taken together, an optimized "lean-burn" direct injection gasoline engine may achieve high engine thermal efficiency which approaches that of a diesel engine. European gasoline direct-injection engines have implemented stratified-charge lean-burn GDI, although at higher NOx emissions levels than are allowed at under U.S. Federal Tier 2 emissions standards. Fuel system improvements, changes in combustion chamber design and repositioning of the injectors have allowed for better air/fuel mixing and combustion efficiency. There is currently a shift from wall-guided injection to spray guided injection, which improves injection precision and targeting towards the spark plug, increasing lean combustion stability. Combined with advances in NOx after-treatment, lean-burn GDI engines may eventually be a possibility in North America.

EPA and NHTSA's current assessment is that the availability of ultra-low sulfur (ULS less than 15 ppm sulfur) gasoline is a key technical requirement for lean-burn GDI engines to meet EPA's Tier 2 NOx emissions standards. Since we do not believe that ULS gasoline will be available during the model years applicable to these rules, the technology was not applied in EPA or NHTSA analyses.

Homogeneous Charge Compression Ignition

Gasoline homogeneous charge compression ignition (HCCI), also referred to as controlled autoignition (CAI), is an alternate engine operating mode that does not rely on a spark event to initiate combustion. The principles are more closely aligned with a diesel combustion cycle, in which the compressed charge exceeds a temperature and pressure necessary for spontaneous autoignition although it differs from diesel by having a homogenous fuel/air charge rather than being a diffusion controlled combustion event. The subsequent combustion event is much shorter in duration with higher thermal efficiency.

An HCCI engine has inherent advantages in its overall efficiency for two main reasons:

- The engine is operated with a higher compression ratio, and with a shorter combustion duration, resulting in a higher thermodynamic efficiency, and
- The engine can be operated virtually unthrottled, even at light loads.
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Combined, these effects have shown an increase in engine brake efficiency (typically 25-28 percent) to greater than 35 percent at the high end of the HCCI operating range.[246]

Criteria pollutant emissions are very favorable during HCCI operation. Lower peak in-cylinder temperatures (due to high dilution) keep engine-out NOx emissions to a minimum – realistically

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[246] "An HCCI Engine Power Plant for a Hybrid Vehicle," Sun, R., R. Thomas and C. Gray, Jr., SAE Technical Paper No. 2004-01-0933, 2004.

below Tier 2 levels without aftertreatment – and particulates are low due to the homogeneous nature of the premixed charge.

Due to the inherent difficulty in maintaining combustion stability without encountering engine knock, HCCI is difficult to control, requiring feedback from in-cylinder pressure sensors and rapid engine control logic to optimize combustion timing, especially considering the transient nature of operating conditions seen in a vehicle. Due to the highly dilute conditions under which gasoline-HCCI combustion is stable, the range of engine loads achievable in a naturally-aspirated engine is somewhat limited. Because of this, it is likely that any commercial application would operate in a "dual-mode" strategy between HCCI and spark ignition combustion modes, in which HCCI would be utilized for best efficiency at light engine loads and spark ignition would be used at higher loads and at idle. This type of dual-mode strategy has already been employed in diesel HCCI engines in Europe and Asia (notably the Toyota Avensis D-Cat and the Nissan light-duty "MK" combustion diesels).

Until recently, gasoline-HCCI technology was considered to still be in the research phase. However, most manufacturers have made public statements about the viability of incorporating HCCI into light-duty passenger vehicles, and have significant vehicle demonstration programs aimed at producing a viable product within the next 5-10 years.

There is widespread opinion as to the fuel consumption reduction potential for HCCI in the literature. Based on confidential manufacturer information, EPA and NHTSA believe that a gasoline HCCI / GDI dual-mode engine might achieve 10-12% reduction in fuel consumption, compared to a comparable SI engine. Despite its promise, application of HCCI in light duty vehicles is not yet ready for the market. It is not anticipated to be seen in volume for at least the next 5-10 years, which is concurrent with many manufacturers' public estimates. NHTSA also noted in its MY 2011 CAFE final rule that the technology will not be available within the time frame considered based on a review of confidential product plan information.

Electric Assist Turbocharging

The Alliance commented in prior rulemakings that global development of electric assist turbo-charging has not demonstrated the fuel efficiency effectiveness of a 12V EAT up to 2kW power levels since the 2004 NESCCAF study, and stated that it saw remote probability of its application over the next decade. While hybrid vehicles lower the incremental hardware requirements for higher-voltage, higher-power EAT systems, NHTSA and EPA agree that significant developmental work is required to demonstrate effective systems and that implementation in significant volumes will not occur in the time frame considered in this rulemaking. Thus, this technology was not included in the NPRM.

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 CAFE model runs.

Cost and effectiveness tables

The tables representing the CAFE model input files for MY 2017 incremental technology costs by vehicle subclass are presented below. The tables have been divided into passenger cars, performance passenger cars, and light trucks to make them easier to read.

Table V-95 Technology Incremental Cost Estimates, Passenger Cars

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (for MY 2017 in 2009 dollars) BY VEHICLE SUBCLASS - PASSENGER CARS					
		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Low Friction Lubricants - Level 1	LUB1	$4	$4	$4	$4
Engine Friction Reduction - Level 1	EFR1	$60	$60	$60	$60
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	$63	$63	$63	$63
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	$46	$46	$46	$91
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	$160	$160	$160	$160
Cylinder Deactivation on SOHC	DEACS	$32	$32	$32	$32
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	$46	$46	$46	$91
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	$44	$44	$44	$87
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	$160	$160	$160	$160
Continuously Variable Valve Lift (CVVL)	CVVL	$258	$258	$258	$258
Cylinder Deactivation on DOHC	DEACD	$32	$32	$32	$32
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$266	$266	$266	$266
Cylinder Deactivation on OHV	DEACO	$204	$204	$204	$204
Variable Valve Actuation - CCP and DVVL on OHV	VVA	$51	$51	$51	$102
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	$266	$266	$266	$266
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	$489	$489	$489	$489
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	$20	$20	$20	$20
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	$615	$615	$615	$615
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	$26	$26	$26	$26
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	$260	$260	$260	$260
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	$439	$439	$439	$439
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	$303	$303	$303	$303
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	$303	$303	$303	$303
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	$303	$303	$303	$303
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	$520	$520	$520	$520
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	$520	$520	$520	$520
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	-$296	-$296	-$296	-$296
Advanced Diesel - Small Displacement	ADSL_SD	$873	$873	$873	$873
Advanced Diesel - Medium Displacement	ADSL_MD	$844	$844	$844	$844
Advanced Diesel - Large Displacement	ADSL_LD	$1,693	$1,693	$1,693	$1,693
6-Speed Manual/Improved Internals	6MAN	$277	$277	$277	$277
High Efficiency Gearbox (Manual)	HETRANSM	$248	$248	$248	$248
Improved Auto. Trans. Controls/Externals	IATC	$61	$61	$61	$61
6-Speed Trans with Improved Internals (Auto)	NAUTO	-$39	-$39	-$39	-$39
6-speed DCT	DCT	-$108	-$108	-$74	-$74
8-Speed Trans (Auto or DCT)	8SPD	$255	$255	$255	$255
High Efficiency Gearbox (Auto or DCT)	HETRANS	$248	$248	$248	$248
Shift Optimizer	SHFTOPT	$1	$1	$1	$1
Electric Power Steering	EPS	$108	$108	$108	$108
Improved Accessories - Level 1	IACC1	$87	$87	$87	$87
Improved Accessories - Level 2	IACC2	$54	$54	$54	$54
12V Micro-Hybrid (Stop-Start)	MHEV	$322	$348	$382	$411
Integrated Starter Generator	ISG	$0	$0	$0	$0
Strong Hybrid - Level 1	SHEV1	$3,526	$3,526	$3,705	$4,261
Conversion from SHEV1 to SHEV2	SHEV1_2	$1,215	$1,215	$1,215	$1,481
Strong Hybrid - Level 2	SHEV2	$3,526	$3,526	$3,705	$4,261
Plug-in Hybrid - 30 mi range	PHEV1	$10,868	$10,868	$11,864	$15,514
Plug-in Hybrid	PHEV2	$0	$0	$0	$0
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$3,001	$3,001	$3,719	$3,998
Electric Vehicle (Early Adopter) - 100 mile range	EV2	$0	$0	$0	$0
Electric Vehicle (Early Adopter) - 150 mile range	EV3	$0	$0	$0	$0
Electric Vehicle (Broad Market) - 150 mile range	EV4	$8,018	$8,018	$9,210	$10,659
Fuel Cell Vehicle	FCV	$0	$0	$0	$0
Mass Reduction - Level 1	MR1	$0.00	$0.11	$0.08	$0.08
Mass Reduction - Level 2	MR2	$0.00	$0.00	$0.35	$0.48
Mass Reduction - Level 3	MR3	$0.00	$0.00	$0.00	$0.94
Mass Reduction - Level 4	MR4	$0.00	$0.00	$0.00	$0.00
Mass Reduction - Level 5	MR5	$0.00	$0.00	$0.00	$0.00
Low Rolling Resistance Tires - Level 1	ROLL1	$7	$7	$7	$7

Low Rolling Resistance Tires - Level 2	ROLL2	$72	$72	$72	$72
Low Rolling Resistance Tires - Level 3	ROLL3	$0	$0	$0	$0
Low Drag Brakes	LDB	$73	$73	$73	$73
Secondary Axle Disconnect	SAX	$96	$96	$96	$96
Aero Drag Reduction, Level 1	AERO1	$48	$48	$48	$48
Aero Drag Reduction, Level 2	AERO2	$162	$162	$162	$162

Table V-96 Technology Incremental Cost Estimates, Performance Passenger Cars

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (for MY 2017 in 2009 dollars) BY VEHICLE SUBCLASS - PERFORMANCE PASSENGER CARS					
		Performance Subcompact Car	Performance Compact Car	Performance Midsize Car	Performance Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Low Friction Lubricants - Level 1	LUB1	$3.96	$3.96	$3.96	$3.96
Engine Friction Reduction - Level 1	EFR1	$59.99	$89.98	$89.98	$119.97
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	$62.84	$94.26	$94.26	$125.68
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	$45.55	$91.10	$91.10	$91.10
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	$160.29	$240.43	$240.43	$320.58
Cylinder Deactivation on SOHC	DEACS	$32.20	$32.20	$32.20	$32.20
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	$45.55	$91.10	$91.10	$91.10
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	$43.50	$87.01	$87.01	$87.01
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	$160.29	$240.43	$240.43	$320.58
Continuously Variable Valve Lift (CVVL)	CVVL	$258.04	$387.05	$387.05	$516.07
Cylinder Deactivation on DOHC	DEACD	$32.20	$32.20	$32.20	$32.20
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$266.18	$399.28	$399.28	$532.37
Cylinder Deactivation on OHV	DEACO	$204.20	$204.20	$204.20	$204.20
Variable Valve Actuation - CCP and DVVL on OHV	VVA	$51.04	$102.08	$102.08	$102.08
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	$266.18	$399.28	$399.28	$532.37
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	$489.04	$489.04	$489.04	$489.04
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	$19.69	$19.69	$19.69	$19.69
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	$615.21	$615.21	$615.21	$615.21
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	$26.06	$26.06	$26.06	$26.06
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	$260.15	$260.15	$260.15	$260.15
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	$438.53	$438.53	$438.53	$438.53
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	$302.52	$302.52	$302.52	$302.52
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	$302.52	$302.52	$302.52	$302.52
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	$302.52	$302.52	$302.52	$302.52
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	$520.31	$520.31	$520.31	$520.31
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	$520.31	$520.31	$520.31	$520.31
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	-$296.18	-$296.18	-$296.18	-$296.18
Advanced Diesel - Small Displacement	ADSL_SD	$872.86	$872.86	$872.86	$872.86
Advanced Diesel - Medium Displacement	ADSL_MD	$843.86	$843.86	$843.86	$843.86
Advanced Diesel - Large Displacement	ADSL_LD	$1,693.45	$1,693.45	$1,693.45	$1,693.45
6-Speed Manual/Improved Internals	6MAN	$276.83	$276.83	$276.83	$276.83
High Efficiency Gearbox (Manual)	HETRANSM	$248.38	$248.38	$248.38	$248.38
Improved Auto. Trans. Controls/Externals	IATC	$61.18	$61.18	$61.18	$61.18
6-Speed Trans with Improved Internals (Auto)	NAUTO	-$38.73	-$38.73	-$38.73	-$38.73
6-speed DCT	DCT	-$73.88	-$73.88	-$73.88	-$73.88
8-Speed Trans (Auto or DCT)	8SPD	$255.18	$255.18	$255.18	$255.18
High Efficiency Gearbox (Auto or DCT)	HETRANS	$248.38	$248.38	$248.38	$248.38
Shift Optimizer	SHFTOPT	$1.24	$1.24	$1.24	$1.24
Electric Power Steering	EPS	$107.55	$107.55	$107.55	$107.55
Improved Accessories - Level 1	IACC1	$87.47	$87.47	$87.47	$87.47
Improved Accessories - Level 2	IACC2	$53.64	$53.64	$53.64	$53.64
12V Micro-Hybrid (Stop-Start)	MHEV	$321.78	$348.10	$382.20	$410.50
Integrated Starter Generator	ISG	$0.00	$0.00	$0.00	$0.00
Strong Hybrid - Level 1	SHEV1	$3,525.62	$3,525.62	$3,704.79	$4,260.90
Conversion from SHEV1 to SHEV2	SHEV1_2	$1,214.99	$1,480.51	$1,480.51	$873.81
Strong Hybrid - Level 2	SHEV2	$3,525.62	$3,525.62	$3,704.79	$4,260.90
Plug-in Hybrid - 30 mi range	PHEV1	$10,868.26	$10,868.26	$11,864.38	$15,513.62
Plug-in Hybrid	PHEV2	$0.00	$0.00	$0.00	$0.00
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$3,001.00	$3,001.00	$3,719.30	$3,997.77
Electric Vehicle (Early Adopter) - 100 mile range	EV2	$0.00	$0.00	$0.00	$0.00
Electric Vehicle (Early Adopter) - 150 mile range	EV3	$0.00	$0.00	$0.00	$0.00
Electric Vehicle (Broad Market) - 150 mile range	EV4	$8,017.69	$8,017.69	$9,209.97	$10,658.97
Fuel Cell Vehicle	FCV	$0.00	$0.00	$0.00	$0.00
Mass Reduction - Level 1	MR1	$0.00	$0.11	$0.08	$0.08
Mass Reduction - Level 2	MR2	$0.00	$0.00	$0.35	$0.48
Mass Reduction - Level 3	MR3	$0.00	$0.00	$0.00	$0.94
Mass Reduction - Level 4	MR4	$0.00	$0.00	$0.00	$0.00
Mass Reduction - Level 5	MR5	$0.00	$0.00	$0.00	$0.00

Low Rolling Resistance Tires - Level 1	ROLL1	$6.59	$6.59	$6.59	$6.59
Low Rolling Resistance Tires - Level 2	ROLL2	$72.44	$72.44	$72.44	$72.44
Low Rolling Resistance Tires - Level 3	ROLL3	$0.00	$0.00	$0.00	$0.00
Low Drag Brakes	LDB	$72.51	$72.51	$72.51	$72.51
Secondary Axle Disconnect	SAX	$96.00	$96.00	$96.00	$96.00
Aero Drag Reduction, Level 1	AERO1	$48.08	$48.08	$48.08	$48.08
Aero Drag Reduction, Level 2	AERO2	$161.63	$161.63	$161.63	$161.63

Table V-97 Technology Incremental Cost Estimates, Light Trucks

VEHICLE TECHNOLOGY ICM COSTS PER VEHICLE (for MY 2017 in 2009 dollars) BY VEHICLE SUBCLASS - LIGHT TRUCKS					
		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Low Friction Lubricants - Level 1	LUB1	$3.96	$3.96	$3.96	$3.96
Engine Friction Reduction - Level 1	EFR1	$89.98	$59.99	$89.98	$119.97
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	$94.26	$62.84	$94.26	$125.68
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	$91.10	$45.55	$91.10	$91.10
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	$240.43	$160.29	$240.43	$320.58
Cylinder Deactivation on SOHC	DEACS	$32.20	$32.20	$32.20	$32.20
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	$91.10	$45.55	$91.10	$91.10
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	$87.01	$43.50	$87.01	$87.01
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	$240.43	$160.29	$240.43	$320.58
Continuously Variable Valve Lift (CVVL)	CVVL	$387.05	$258.04	$387.05	$516.07
Cylinder Deactivation on DOHC	DEACD	$32.20	$32.20	$32.20	$32.20
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$399.28	$266.18	$399.28	$532.37
Cylinder Deactivation on OHV	DEACO	$204.20	$204.20	$204.20	$204.20
Variable Valve Actuation - CCP and DVVL on OHV	VVA	$102.08	$51.04	$102.08	$102.08
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	$399.28	$266.18	$399.28	$532.37
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	$489.04	$489.04	$489.04	$489.04
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	$19.69	$19.69	$19.69	$19.69
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	$615.21	$615.21	$615.21	$615.21
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	$26.06	$26.06	$26.06	$26.06
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	$260.15	$260.15	$260.15	$260.15
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	$438.53	$438.53	$438.53	$438.53
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	$302.52	$302.52	$302.52	$302.52
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	$302.52	$302.52	$302.52	$302.52
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	$302.52	$302.52	$302.52	$302.52
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	$520.31	$520.31	$520.31	$520.31
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	$520.31	$520.31	$520.31	$520.31
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	-$296.18	-$296.18	-$296.18	-$296.18
Advanced Diesel - Small Displacement	ADSL_SD	$872.86	$872.86	$872.86	$872.86
Advanced Diesel - Medium Displacement	ADSL_MD	$843.86	$843.86	$843.86	$843.86
Advanced Diesel - Large Displacement	ADSL_LD	$1,693.45	$1,693.45	$1,693.45	$1,693.45
6-Speed Manual/Improved Internals	6MAN	$276.83	$276.83	$276.83	$276.83
High Efficiency Gearbox (Manual)	HETRANSM	$248.38	$248.38	$248.38	$248.38
Improved Auto. Trans. Controls/Externals	IATC	$61.18	$61.18	$61.18	$61.18
6-Speed Trans with Improved Internals (Auto)	NAUTO	-$38.73	-$38.73	-$38.73	-$38.73
6-speed DCT	DCT	$0.00	-$73.88	$0.00	$0.00
8-Speed Trans (Auto or DCT)	8SPD	$79.64	$255.18	$79.64	$79.64
High Efficiency Gearbox (Auto or DCT)	HETRANS	$248.38	$248.38	$248.38	$248.38
Shift Optimizer	SHFTOPT	$1.24	$1.24	$1.24	$1.24
Electric Power Steering	EPS	$107.55	$107.55	$107.55	$107.55
Improved Accessories - Level 1	IACC1	$87.47	$87.47	$87.47	$87.47
Improved Accessories - Level 2	IACC2	$53.64	$53.64	$53.64	$53.64
12V Micro-Hybrid (Stop-Start)	MHEV	$410.50	$363.07	$420.58	$475.52
Integrated Starter Generator	ISG	$0.00	$0.00	$0.00	$0.00
Strong Hybrid - Level 1	SHEV1	$4,332.17	$4,056.71	$4,332.17	$4,464.69
Conversion from SHEV1 to SHEV2	SHEV1_2	$1,480.51	$1,214.99	$1,480.51	$873.81
Strong Hybrid - Level 2	SHEV2	$4,332.17	$4,056.71	$4,332.17	$4,464.69
Plug-in Hybrid - 30 mi range	PHEV1	$0.00	$14,054.94	$0.00	$0.00
Plug-in Hybrid	PHEV2	$0.00	$0.00	$0.00	$0.00
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$0.00	$4,580.10	$0.00	$0.00
Electric Vehicle (Early Adopter) - 100 mile range	EV2	$0.00	$0.00	$0.00	$0.00
Electric Vehicle (Early Adopter) - 150 mile range	EV3	$0.00	$0.00	$0.00	$0.00
Electric Vehicle (Broad Market) - 150 mile range	EV4	$0.00	$12,413.28	$0.00	$0.00
Fuel Cell Vehicle	FCV	$0.00	$0.00	$0.00	$0.00

Mass Reduction - Level 1	MR1	$0.08	$0.08	$0.08	$0.08
Mass Reduction - Level 2	MR2	$0.48	$0.48	$0.48	$0.48
Mass Reduction - Level 3	MR3	$0.94	$0.94	$0.94	$0.94
Mass Reduction - Level 4	MR4	$1.50	$1.50	$1.50	$1.50
Mass Reduction - Level 5	MR5	$2.10	$2.10	$2.10	$2.10
Low Rolling Resistance Tires - Level 1	ROLL1	$6.59	$6.59	$6.59	$6.59
Low Rolling Resistance Tires - Level 2	ROLL2	$72.44	$72.44	$72.44	$72.44
Low Rolling Resistance Tires - Level 3	ROLL3	$0.00	$0.00	$0.00	$0.00
Low Drag Brakes	LDB	$72.51	$72.51	$72.51	$72.51
Secondary Axle Disconnect	SAX	$96.00	$96.00	$96.00	$96.00
Aero Drag Reduction, Level 1	AERO1	$48.08	$48.08	$48.08	$48.08
Aero Drag Reduction, Level 2	AERO2	$161.63	$161.63	$161.63	$161.63

The tables representing the CAFE model input files for incremental technology effectiveness values by vehicle subclass are presented below. The tables have been divided into passenger cars, performance passenger cars, and light trucks to make them easier to read.

Table V-98 Technology Incremental Effectiveness Estimates, Passenger Cars

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%) BY VEHICLE SUBCLASS - PASSENGER CARS					
		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Low Friction Lubricants - Level 1	LUB1	0.50%	0.50%	0.70%	0.80%
Engine Friction Reduction - Level 1	EFR1	2.00%	2.00%	2.60%	2.70%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	1.04%	1.04%	1.26%	1.37%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	4.15%	4.15%	5.03%	5.36%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	2.81%	2.81%	3.64%	3.88%
Cylinder Deactivation on SOHC	DEACS	0.44%	0.44%	0.69%	0.69%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	2.18%	2.18%	2.62%	2.73%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	2.01%	2.01%	2.47%	2.70%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	2.81%	2.81%	3.64%	3.88%
Continuously Variable Valve Lift (CVVL)	CVVL	3.57%	3.57%	4.63%	4.88%
Cylinder Deactivation on DOHC	DEACD	0.44%	0.44%	0.69%	0.69%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.56%	1.56%	1.50%	1.51%
Cylinder Deactivation on OHV	DEACO	4.66%	4.66%	5.86%	6.30%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	2.72%	2.72%	3.45%	3.59%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	1.56%	1.56%	1.50%	1.51%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	7.20%	7.20%	8.29%	8.61%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	6.70%	6.70%	7.49%	7.79%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	6.70%	6.70%	7.49%	7.79%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	2.92%	2.92%	3.54%	3.71%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	2.92%	2.92%	3.54%	3.71%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	2.92%	2.92%	3.54%	3.71%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	3.63%	3.63%	3.54%	3.46%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3.63%	3.63%	3.54%	3.46%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	3.63%	3.63%	3.54%	3.46%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	1.04%	1.04%	1.36%	1.38%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	1.04%	1.04%	1.36%	1.38%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	1.04%	1.04%	1.36%	1.38%
Advanced Diesel - Small Displacement	ADSL_SD	5.53%	5.53%	2.75%	2.89%
Advanced Diesel - Medium Displacement	ADSL_MD	5.53%	5.53%	2.75%	2.89%
Advanced Diesel - Large Displacement	ADSL_LD	5.53%	5.53%	2.75%	2.89%
6-Speed Manual/Improved Internals	6MAN	2.02%	2.02%	2.39%	2.34%
High Efficiency Gearbox (Manual)	HETRANSM	3.44%	3.44%	4.08%	3.85%
Improved Auto. Trans. Controls/Externals	IATC	2.30%	2.30%	3.00%	3.10%
6-Speed Trans with Improved Internals (Auto)	NAUTO	1.89%	1.89%	2.04%	2.04%
6-speed DCT	DCT	4.01%	4.01%	4.06%	3.75%
8-Speed Trans (Auto or DCT)	8SPD	3.85%	3.85%	4.57%	4.56%
High Efficiency Gearbox (Auto or DCT)	HETRANS	2.17%	2.17%	2.68%	2.56%
Shift Optimizer	SHFTOPT	3.27%	3.27%	4.08%	4.31%
Electric Power Steering	EPS	1.50%	1.50%	1.30%	1.10%
Improved Accessories - Level 1	IACC1	1.22%	1.22%	1.22%	1.01%
Improved Accessories - Level 2	IACC2	1.85%	1.85%	2.36%	2.55%
12V Micro-Hybrid (Stop-Start)	MHEV	1.68%	1.68%	2.10%	2.20%
Integrated Starter Generator	ISG	0.00%	0.00%	0.00%	0.00%
Strong Hybrid - Level 1	SHEV1	14.86%	14.86%	11.65%	12.45%
Conversion from SHEV1 to SHEV2	SHEV1_2	10.03%	10.03%	12.44%	12.46%
Strong Hybrid - Level 2	SHEV2	10.07%	10.07%	6.47%	6.83%
Plug-in Hybrid - 30 mi range	PHEV1	40.65%	40.65%	40.65%	40.65%
Plug-in Hybrid	PHEV2	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	68.54%	68.54%	68.54%	68.54%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0.00%	0.00%	0.00%	0.00%
Fuel Cell Vehicle	FCV	0.00%	0.00%	0.00%	0.00%
Mass Reduction - Level 1	MR1	0.00%	0.70%	0.53%	0.53%

Mass Reduction - Level 2	MR2	0.00%	0.00%	2.04%	3.32%
Mass Reduction - Level 3	MR3	0.00%	0.00%	0.00%	1.33%
Mass Reduction - Level 4	MR4	0.00%	0.00%	0.00%	0.00%
Mass Reduction - Level 5	MR5	0.00%	0.00%	0.00%	0.00%
Low Rolling Resistance Tires - Level 1	ROLL1	1.90%	1.90%	1.90%	1.90%
Low Rolling Resistance Tires - Level 2	ROLL2	2.04%	2.04%	2.04%	2.04%
Low Rolling Resistance Tires - Level 3	ROLL3	0.00%	0.00%	0.00%	0.00%
Low Drag Brakes	LDB	0.80%	0.80%	0.80%	0.80%
Secondary Axle Disconnect	SAX	1.40%	1.40%	1.40%	1.30%
Aero Drag Reduction, Level 1	AERO1	2.30%	2.30%	2.30%	2.30%
Aero Drag Reduction, Level 2	AERO2	2.46%	2.46%	2.46%	2.46%

Table V-99 Technology Incremental Effectiveness Estimates, Performance Cars

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%) BY VEHICLE SUBCLASS - PERFORMANCE PASSENGER CARS					
		Performance Subcompact Car	Performance Compact Car	Performance Midsize Car	Performance Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Low Friction Lubricants - Level 1	LUB1	0.50%	0.50%	0.70%	0.80%
Engine Friction Reduction - Level 1	EFR1	2.00%	2.00%	2.60%	2.70%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	1.04%	1.04%	1.26%	1.37%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	4.15%	4.15%	5.03%	5.36%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	2.81%	2.81%	3.64%	3.88%
Cylinder Deactivation on SOHC	DEACS	0.44%	0.44%	0.69%	0.69%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	2.18%	2.18%	2.62%	2.73%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	2.01%	2.01%	2.47%	2.70%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	2.81%	2.81%	3.64%	3.88%
Continuously Variable Valve Lift (CVVL)	CVVL	3.57%	3.57%	4.63%	4.88%
Cylinder Deactivation on DOHC	DEACD	0.44%	0.44%	0.69%	0.69%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.56%	1.56%	1.50%	1.51%
Cylinder Deactivation on OHV	DEACO	4.66%	4.66%	5.86%	6.30%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	2.72%	2.72%	3.45%	3.59%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	1.56%	1.56%	1.50%	1.51%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	7.20%	7.20%	8.29%	8.61%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	6.70%	6.70%	7.49%	7.79%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	6.70%	6.70%	7.49%	7.79%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	2.92%	2.92%	3.54%	3.71%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	2.92%	2.92%	3.54%	3.71%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	2.92%	2.92%	3.54%	3.71%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	3.63%	3.63%	3.54%	3.46%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3.63%	3.63%	3.54%	3.46%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	3.63%	3.63%	3.54%	3.46%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	1.04%	1.04%	1.36%	1.38%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	1.04%	1.04%	1.36%	1.38%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	1.04%	1.04%	1.36%	1.38%
Advanced Diesel - Small Displacement	ADSL_SD	5.53%	5.53%	2.75%	2.89%
Advanced Diesel - Medium Displacement	ADSL_MD	5.53%	5.53%	2.75%	2.89%
Advanced Diesel - Large Displacement	ADSL_LD	5.53%	5.53%	2.75%	2.89%
6-Speed Manual/Improved Internals	6MAN	2.02%	2.02%	2.39%	2.34%
High Efficiency Gearbox (Manual)	HETRANSM	3.44%	3.44%	4.08%	3.85%
Improved Auto. Trans. Controls/Externals	IATC	2.30%	2.30%	3.00%	3.10%
6-Speed Trans with Improved Internals (Auto)	NAUTO	1.89%	1.89%	2.04%	2.04%
6-speed DCT	DCT	3.38%	3.38%	4.06%	3.75%
8-Speed Trans (Auto or DCT)	8SPD	4.48%	4.48%	4.57%	4.56%
High Efficiency Gearbox (Auto or DCT)	HETRANS	2.17%	2.17%	2.68%	2.56%
Shift Optimizer	SHFTOPT	3.27%	3.27%	4.08%	4.31%
Electric Power Steering	EPS	1.50%	1.50%	1.30%	1.10%
Improved Accessories - Level 1	IACC1	1.22%	1.22%	1.22%	1.01%
Improved Accessories - Level 2	IACC2	1.85%	1.85%	2.36%	2.55%
12V Micro-Hybrid (Stop-Start)	MHEV	1.68%	1.68%	2.10%	2.20%
Integrated Starter Generator	ISG	0.00%	0.00%	0.00%	0.00%
Strong Hybrid - Level 1	SHEV1	14.86%	14.86%	11.65%	12.45%
Conversion from SHEV1 to SHEV2	SHEV1_2	10.45%	10.45%	12.44%	12.46%
Strong Hybrid - Level 2	SHEV2	9.74%	9.74%	6.47%	6.83%
Plug-in Hybrid - 30 mi range	PHEV1	40.65%	40.65%	40.65%	40.65%
Plug-in Hybrid	PHEV2	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	68.54%	68.54%	68.54%	68.54%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0.00%	0.00%	0.00%	0.00%
Fuel Cell Vehicle	FCV	0.00%	0.00%	0.00%	0.00%
Mass Reduction - Level 1	MR1	0.00%	0.70%	0.53%	0.53%
Mass Reduction - Level 2	MR2	0.00%	0.00%	2.04%	3.32%
Mass Reduction - Level 3	MR3	0.00%	0.00%	0.00%	1.33%

Mass Reduction - Level 4	MR4	0.00%	0.00%	0.00%	0.00%
Mass Reduction - Level 5	MR5	0.00%	0.00%	0.00%	0.00%
Low Rolling Resistance Tires - Level 1	ROLL1	1.90%	1.90%	1.90%	1.90%
Low Rolling Resistance Tires - Level 2	ROLL2	2.04%	2.04%	2.04%	2.04%
Low Rolling Resistance Tires - Level 3	ROLL3	0.00%	0.00%	0.00%	0.00%
Low Drag Brakes	LDB	0.80%	0.80%	0.80%	0.80%
Secondary Axle Disconnect	SAX	1.40%	1.40%	1.40%	1.30%
Aero Drag Reduction, Level 1	AERO1	2.30%	2.30%	2.30%	2.30%
Aero Drag Reduction, Level 2	AERO2	2.46%	2.46%	2.46%	2.46%

Table V-100 Technology Incremental Effectiveness Estimates, Light Trucks

VEHICLE TECHNOLOGY INCREMENTAL FUEL CONSUMPTION REDUCTION (-%) BY VEHICLE SUBCLASS - LIGHT TRUCKS					
		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Low Friction Lubricants - Level 1	LUB1	0.70%	0.60%	0.70%	0.70%
Engine Friction Reduction - Level 1	EFR1	2.60%	2.00%	2.60%	2.40%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	1.26%	0.83%	1.26%	1.15%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	5.03%	4.14%	5.03%	4.80%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	3.53%	2.81%	3.53%	3.40%
Cylinder Deactivation on SOHC	DEACS	0.69%	0.44%	0.69%	0.57%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	2.51%	2.17%	2.51%	2.51%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	2.58%	2.01%	2.58%	2.36%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	3.53%	2.81%	3.53%	3.40%
Continuously Variable Valve Lift (CVVL)	CVVL	4.52%	3.56%	4.52%	4.28%
Cylinder Deactivation on DOHC	DEACD	0.69%	0.44%	0.69%	0.57%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1.50%	1.56%	1.50%	1.48%
Cylinder Deactivation on OHV	DEACO	5.86%	4.66%	5.86%	5.53%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	3.34%	2.71%	3.34%	3.20%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	1.50%	1.56%	1.50%	1.48%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	8.74%	7.08%	8.74%	7.96%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	7.94%	6.58%	7.94%	7.30%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	7.94%	6.58%	7.94%	7.30%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	3.43%	2.91%	3.43%	3.38%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	3.43%	2.91%	3.43%	3.38%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	3.43%	2.91%	3.43%	3.38%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	3.55%	3.63%	3.55%	3.62%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3.55%	3.63%	3.55%	3.62%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	3.55%	3.63%	3.55%	3.62%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	1.09%	1.04%	1.09%	1.21%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	1.09%	1.04%	1.09%	1.21%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	1.09%	1.04%	1.09%	1.21%
Advanced Diesel - Small Displacement	ADSL_SD	3.44%	5.31%	3.44%	3.48%
Advanced Diesel - Medium Displacement	ADSL_MD	3.44%	5.31%	3.44%	3.48%
Advanced Diesel - Large Displacement	ADSL_LD	3.44%	5.31%	3.44%	3.48%
6-Speed Manual/Improved Internals	6MAN	2.24%	2.21%	2.24%	2.52%
High Efficiency Gearbox (Manual)	HETRANSM	3.71%	3.90%	3.71%	4.45%
Improved Auto. Trans. Controls/Externals	IATC	2.90%	2.40%	2.90%	2.90%
6-Speed Trans with Improved Internals (Auto)	NAUTO	2.03%	2.00%	2.03%	2.13%
6-speed DCT	DCT	0.00%	3.81%	0.00%	0.00%
8-Speed Trans (Auto or DCT)	8SPD	4.90%	4.18%	4.90%	5.34%
High Efficiency Gearbox (Auto or DCT)	HETRANS	3.14%	2.52%	3.14%	3.72%
Shift Optimizer	SHFTOPT	4.05%	3.29%	4.05%	3.86%
Electric Power Steering	EPS	1.00%	1.20%	1.00%	0.80%
Improved Accessories - Level 1	IACC1	0.91%	1.01%	0.91%	1.61%
Improved Accessories - Level 2	IACC2	2.34%	1.74%	2.34%	2.15%
12V Micro-Hybrid (Stop-Start)	MHEV	2.09%	1.77%	2.09%	2.09%
Integrated Starter Generator	ISG	0.00%	0.00%	0.00%	0.00%
Strong Hybrid - Level 1	SHEV1	5.43%	13.97%	5.43%	3.73%
Conversion from SHEV1 to SHEV2	SHEV1_2	17.10%	10.91%	17.10%	17.94%
Strong Hybrid - Level 2	SHEV2	5.16%	9.96%	8.15%	7.33%
Plug-in Hybrid - 30 mi range	PHEV1	40.65%	40.65%	40.65%	40.65%
Plug-in Hybrid	PHEV2	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	68.54%	68.54%	68.54%	68.54%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0.00%	0.00%	0.00%	0.00%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0.00%	0.00%	0.00%	0.00%
Fuel Cell Vehicle	FCV	0.00%	0.00%	0.00%	0.00%
Mass Reduction - Level 1	MR1	0.53%	0.53%	0.53%	0.53%
Mass Reduction - Level 2	MR2	3.32%	3.32%	3.32%	3.32%
Mass Reduction - Level 3	MR3	1.33%	1.33%	1.33%	1.33%
Mass Reduction - Level 4	MR4	2.69%	2.69%	2.69%	2.69%

Mass Reduction - Level 5	MR5	2.76%	2.76%	2.76%	2.76%
Low Rolling Resistance Tires - Level 1	ROLL1	1.90%	1.90%	1.90%	1.90%
Low Rolling Resistance Tires - Level 2	ROLL2	2.04%	2.04%	2.04%	2.04%
Low Rolling Resistance Tires - Level 3	ROLL3	0.00%	0.00%	0.00%	0.00%
Low Drag Brakes	LDB	0.80%	0.80%	0.80%	0.80%
Secondary Axle Disconnect	SAX	1.30%	1.40%	1.30%	1.60%
Aero Drag Reduction, Level 1	AERO1	2.30%	2.30%	2.30%	2.30%
Aero Drag Reduction, Level 2	AERO2	2.46%	2.46%	2.46%	2.46%

The tables representing the CAFE model input files for MY 2017, MY 2021 and MY 2025 approximate net (accumulated) technology costs by vehicle subclass are presented below. The tables have been divided into passenger cars, performance passenger cars, and light trucks to make them easier to read.

Table V-101. MY 2017 Approximate Net (Accumulated) Technology Costs, Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2017 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$631	$631	$631	$951
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$1,120	$1,120	$1,120	$971
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,146	$1,146	$1,146	$1,231
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,449	$1,449	$1,449	$1,534
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,969	$1,969	$1,969	$2,054
Advanced Diesel	ADSL	$2,842	$2,842	$2,842	$2,898
6-speed DCT	DCT	-$85	-$85	-$51	-$51
8-Speed Trans (Auto or DCT)	8SPD	$170	$170	$204	$204
Shift Optimizer	SHFTOPT	$420	$420	$453	$453
12V Micro-Hybrid (Stop-Start)	MHEV	$570	$597	$631	$659
Strong Hybrid - Level 2	SHEV2	$6,485	$6,511	$6,758	$7,427
Plug-in Hybrid - 30 mi range	PHEV1	$17,353	$17,379	$18,622	$22,941
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$20,354	$20,380	$22,342	$26,939
Electric Vehicle (Broad Market) - 150 mile range	EV4	$28,371	$28,398	$31,552	$37,598

Table V-102 MY 2017 Approximate Net (Accumulated) Technology Costs, Performance Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2017 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Performance Subcompact Car	Performance Compact Car	Performance Midsize Car	Performance Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$631	$951	$951	$1,226
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$1,120	$971	$971	$1,841
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,146	$1,231	$1,231	$2,280
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,449	$1,534	$1,534	$2,582
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,969	$2,054	$2,054	$2,286
Advanced Diesel	ADSL	$2,842	$2,898	$2,898	$3,979
6-speed DCT	DCT	-$51	-$51	-$51	-$51
8-Speed Trans (Auto or DCT)	8SPD	$204	$204	$204	$204
Shift Optimizer	SHFTOPT	$453	$453	$453	$453
12V Micro-Hybrid (Stop-Start)	MHEV	$570	$597	$631	$659
Strong Hybrid - Level 2	SHEV2	$6,518	$6,630	$6,843	$7,659
Plug-in Hybrid - 30 mi range	PHEV1	$17,387	$17,498	$18,707	$23,173
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$20,388	$20,499	$22,427	$27,171
Electric Vehicle (Broad Market) - 150 mile range	EV4	$28,405	$28,517	$31,637	$37,830

Table V-103 MY 2017 Approximate Net (Accumulated) Technology Costs, Light Trucks

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2017 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$951	$631	$951	$1,226
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$971	$1,120	$971	$1,841
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,231	$1,146	$1,231	$2,280
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,534	$1,449	$1,534	$2,582
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$2,054	$1,969	$2,054	$2,286
Advanced Diesel	ADSL	$2,898	$2,842	$2,898	$3,979
6-speed DCT	DCT	$22	-$51	$22	$22
8-Speed Trans (Auto or DCT)	8SPD	$102	$204	$102	$102
Shift Optimizer	SHFTOPT	$352	$453	$352	$352
12V Micro-Hybrid (Stop-Start)	MHEV	$659	$612	$669	$724
Strong Hybrid - Level 2	SHEV2	$7,397	$7,091	$7,407	$7,827
Plug-in Hybrid - 30 mi range	PHEV1	-	$21,146	-	-
Electric Vehicle (Early Adopter) - 75 mile range	EV1	-	$25,726	-	-
Electric Vehicle (Broad Market) - 150 mile range	EV4	-	$38,139	-	-

Table V-104 MY 2021 Approximate Net (Accumulated) Technology Costs, Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2021 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$564	$564	$564	$850
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$980	$980	$980	$821
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,000	$1,000	$1,000	$1,067
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,285	$1,285	$1,285	$1,352
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,776	$1,776	$1,776	$1,843
Advanced Diesel	ADSL	$2,672	$2,672	$2,672	$2,759
6-speed DCT	DCT	-$97	-$97	-$61	-$61
8-Speed Trans (Auto or DCT)	8SPD	$124	$124	$160	$160
Shift Optimizer	SHFTOPT	$351	$351	$386	$386
12V Micro-Hybrid (Stop-Start)	MHEV	$497	$519	$548	$571
Strong Hybrid - Level 2	SHEV2	$5,582	$5,604	$5,821	$6,377
Plug-in Hybrid - 30 mi range	PHEV1	$13,686	$13,708	$14,661	$17,947
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$15,723	$15,745	$17,312	$20,855
Electric Vehicle (Broad Market) - 150 mile range	EV4	$21,575	$21,598	$24,032	$28,633

Table V-105 MY 2021 Approximate Net (Accumulated) Technology Costs, Performance Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2021 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Performance Subcompact Car	Performance Compact Car	Performance Midsize Car	Performance Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$564	$850	$850	$1,095
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$980	$821	$821	$1,614
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,000	$1,067	$1,067	$2,028
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,285	$1,352	$1,352	$2,313
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,776	$1,843	$1,843	$2,020
Advanced Diesel	ADSL	$2,672	$2,759	$2,759	$3,814
6-speed DCT	DCT	-$61	-$61	-$61	-$61
8-Speed Trans (Auto or DCT)	8SPD	$160	$160	$160	$160
Shift Optimizer	SHFTOPT	$386	$386	$386	$386
12V Micro-Hybrid (Stop-Start)	MHEV	$497	$519	$548	$571
Strong Hybrid - Level 2	SHEV2	$5,618	$5,707	$5,888	$6,554
Plug-in Hybrid - 30 mi range	PHEV1	$13,722	$13,811	$14,728	$18,124
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$15,759	$15,848	$17,379	$21,032
Electric Vehicle (Broad Market) - 150 mile range	EV4	$21,611	$21,701	$24,099	$28,810

Table V-106 MY 2021 Approximate Net (Accumulated) Technology Costs, Light Trucks

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2021 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$850	$564	$850	$1,095
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$821	$980	$821	$1,614
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,067	$1,000	$1,067	$2,028
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,352	$1,285	$1,352	$2,313
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,843	$1,776	$1,843	$2,020
Advanced Diesel	ADSL	$2,759	$2,672	$2,759	$3,814
6-speed DCT	DCT	$17	-$61	$17	$17
8-Speed Trans (Auto or DCT)	8SPD	$86	$160	$86	$86
Shift Optimizer	SHFTOPT	$313	$386	$313	$313
12V Micro-Hybrid (Stop-Start)	MHEV	$571	$531	$580	$626
Strong Hybrid - Level 2	SHEV2	$6,372	$6,098	$6,381	$6,717
Plug-in Hybrid - 30 mi range	PHEV1	-	$16,567	-	-
Electric Vehicle (Early Adopter) - 75 mile range	EV1	-	$19,935	-	-
Electric Vehicle (Broad Market) - 150 mile range	EV4	-	$29,004	-	-

Table V-107 MY 2025 Approximate Net (Accumulated) Technology Costs, Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2025 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$535	$535	$535	$806
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$929	$929	$929	$789
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$934	$934	$934	$1,001
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,181	$1,181	$1,181	$1,248
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,606	$1,606	$1,606	$1,673
Advanced Diesel	ADSL	$2,295	$2,295	$2,295	$2,392
6-speed DCT	DCT	-$84	-$84	-$52	-$52
8-Speed Trans (Auto or DCT)	8SPD	$125	$125	$157	$157
Shift Optimizer	SHFTOPT	$326	$326	$357	$357
12V Micro-Hybrid (Stop-Start)	MHEV	$456	$476	$503	$524
Strong Hybrid - Level 2	SHEV2	$5,009	$5,030	$5,220	$5,724
Plug-in Hybrid - 30 mi range	PHEV1	$11,479	$11,499	$12,282	$15,015
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$12,307	$12,327	$13,517	$16,184
Electric Vehicle (Broad Market) - 150 mile range	EV4	$16,604	$16,624	$18,450	$21,895

Table V-108 MY 2025 Approximate Net (Accumulated) Technology Costs, Performance Passenger Cars

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2025 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Performance Subcompact Car	Performance Compact Car	Performance Midsize Car	Performance Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$535	$806	$806	$1,039
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$929	$789	$789	$1,528
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$934	$1,001	$1,001	$1,886
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,181	$1,248	$1,248	$2,133
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,606	$1,673	$1,673	$1,847
Advanced Diesel	ADSL	$2,295	$2,392	$2,392	$3,335
6-speed DCT	DCT	-$52	-$52	-$52	-$52
8-Speed Trans (Auto or DCT)	8SPD	$157	$157	$157	$157
Shift Optimizer	SHFTOPT	$357	$357	$357	$357
12V Micro-Hybrid (Stop-Start)	MHEV	$456	$476	$503	$524
Strong Hybrid - Level 2	SHEV2	$5,041	$5,129	$5,288	$5,898
Plug-in Hybrid - 30 mi range	PHEV1	$11,511	$11,599	$12,350	$15,189
Electric Vehicle (Early Adopter) - 75 mile range	EV1	$12,339	$12,426	$13,584	$16,358
Electric Vehicle (Broad Market) - 150 mile range	EV4	$16,636	$16,723	$18,518	$22,069

Table V-109 MY 2025 Approximate Net (Accumulated) Technology Costs, Light Trucks

APPROXIMATE ICM NET COSTS PER VEHICLE (for MY 2025 in 2009 dollars) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	$806	$535	$806	$1,039
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	$789	$929	$789	$1,528
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	$1,001	$934	$1,001	$1,886
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	$1,248	$1,181	$1,248	$2,133
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	$1,673	$1,606	$1,673	$1,847
Advanced Diesel	ADSL	$2,392	$2,295	$2,392	$3,335
6-speed DCT	DCT	$18	-$52	$18	$18
8-Speed Trans (Auto or DCT)	8SPD	$83	$157	$83	$83
Shift Optimizer	SHFTOPT	$284	$357	$284	$284
12V Micro-Hybrid (Stop-Start)	MHEV	$524	$488	$532	$574
Strong Hybrid - Level 2	SHEV2	$5,700	$5,468	$5,707	$6,022
Plug-in Hybrid - 30 mi range	PHEV1	-	$13,837	-	-
Electric Vehicle (Early Adopter) - 75 mile range	EV1	-	$15,478	-	-
Electric Vehicle (Broad Market) - 150 mile range	EV4	-	$22,139	-	-

The tables representing the CAFE model input files for approximate net (accumulated) technology effectiveness values by vehicle subclass are presented below. The tables have been divided into passenger cars, performance passenger cars, and light trucks to make them easier to read.

Table V-110 Approximate Net Technology Effectiveness, Passenger Cars

APPROXIMATE NET EFFECTIVENESS ESTIMATES (FC REDUCTION) PER VEHILCE (-%) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Subcompact Car	Compact Car	Midsize Car	Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	Inline 4	Inline 4	V6
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	11.9%	11.9%	14.5%	15.3%
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	17.8%	17.8%	20.9%	21.9%
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	20.2%	20.2%	23.7%	24.8%
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	23.1%	23.1%	26.4%	27.4%
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	23.9%	23.9%	27.4%	28.4%
Advanced Diesel	ADSL	28.1%	28.1%	29.4%	30.5%
6-speed DCT	DCT	8.0%	8.0%	8.8%	8.6%
8-Speed Trans (Auto or DCT)	8SPD	11.5%	11.5%	13.0%	12.8%
Shift Optimizer	SHFTOPT	16.3%	16.3%	18.8%	18.7%
12V Micro-Hybrid (Stop-Start)	MHEV	6.1%	6.1%	6.8%	6.7%
Strong Hybrid - Level 2	SHEV2	46.2%	46.2%	48.6%	49.4%
Plug-in Hybrid - 30 mi range	PHEV1	68.1%	68.1%	69.5%	70.0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	90.0%	90.0%	90.4%	90.6%
Electric Vehicle (Broad Market) - 150 mile range	EV4	90.0%	90.0%	90.4%	90.6%

Table V-111 Approximate Net Technology Effectiveness, Performance Passenger Cars

APPROXIMATE NET EFFECTIVENESS ESTIMATES (FC REDUCTION) PER VEHILCE (-%) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Performance Subcompact Car	Performance Compact Car	Performance Midsize Car	Performance Large Car
Nominal Baseline Engine (For Cost Basis)		Inline 4	V6	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	11.9%	11.9%	14.5%	15.3%
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	17.8%	17.8%	20.9%	21.9%
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	20.2%	20.2%	23.7%	24.8%
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	23.1%	23.1%	26.4%	27.4%
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	23.9%	23.9%	27.4%	28.4%
Advanced Diesel	ADSL	28.1%	28.1%	29.4%	30.5%
6-speed DCT	DCT	7.4%	7.4%	8.8%	8.6%
8-Speed Trans (Auto or DCT)	8SPD	11.5%	11.5%	13.0%	12.8%
Shift Optimizer	SHFTOPT	16.3%	16.3%	18.8%	18.7%
12V Micro-Hybrid (Stop-Start)	MHEV	6.1%	6.1%	6.8%	6.7%
Strong Hybrid - Level 2	SHEV2	46.0%	46.0%	48.6%	49.4%
Plug-in Hybrid - 30 mi range	PHEV1	68.0%	68.0%	69.5%	70.0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	89.9%	89.9%	90.4%	90.6%
Electric Vehicle (Broad Market) - 150 mile range	EV4	89.9%	89.9%	90.4%	90.6%

Table V-112 Approximate Net Technology Effectiveness, Light Trucks

APPROXIMATE NET EFFECTIVENESS ESTIMATES (FC REDUCTION) PER VEHILCE (-%) BY VEHICLE SUBCLASS TO KEY TECHNOLOGIES					
Final technology (as compared to baseline vehicle prior to technology application)		Minivan LT	Small LT	Midsize LT	Large LT
Nominal Baseline Engine (For Cost Basis)		V6	Inline 4	V6	V8
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	14.4%	11.8%	14.4%	13.7%
Turbocharging and Downsizing - Level 1 (18 bar BMEP)	TRBDS1	21.2%	17.6%	21.2%	20.0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP)	TRBDS2	23.9%	20.0%	23.9%	22.7%
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP)	CEGR1	26.6%	22.9%	26.6%	25.5%
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP)	CEGR2	27.4%	23.7%	27.4%	26.4%
Advanced Diesel	ADSL	29.9%	27.8%	29.9%	29.0%
6-speed DCT	DCT	4.9%	8.0%	4.9%	5.0%
8-Speed Trans (Auto or DCT)	8SPD	9.5%	11.8%	9.5%	10.0%
Shift Optimizer	SHFTOPT	15.9%	16.9%	15.9%	16.7%
12V Micro-Hybrid (Stop-Start)	MHEV	6.2%	5.6%	6.2%	6.5%
Strong Hybrid - Level 2	SHEV2	45.7%	46.1%	45.7%	45.1%
Plug-in Hybrid - 30 mi range	PHEV1	-	68.0%	-	-
Electric Vehicle (Early Adopter) - 75 mile range	EV1	-	89.9%	-	-
Electric Vehicle (Broad Market) - 150 mile range	EV4	-	89.9%	-	-

C. Penetration of Technologies by Alternative

Table V-113 shows the penetration of technologies by alternative for passenger cars, Table V-114 shows the penetration of technologies for light trucks for the alternatives and Table V-115 shows the penetration of technologies by alternative for the combined passenger car and light truck fleet. These tables are for the whole fleet combined, not by specific manufacturers. The application rate only includes technologies that the model applied. The penetration rate includes technologies that the model applies and technologies that were already present in the base fleet/base vehicle. They allow the reader to see the progression of technologies used as the alternatives get stricter.

Table V-113. Penetration Rate of New Technologies to Passenger Cars, by Alternative

Preferred Alternative - Passenger Cars										
Technology	**Abbr.**	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Low Friction Lubricants - Level 1	LUB1	81%	89%	89%	89%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	80%	85%	88%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	12%	22%	34%	42%	53%	58%	61%	68%	70%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	7%	8%	10%	10%	10%	10%	10%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	11%	11%	11%	12%	11%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	19%	13%	9%	7%	4%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	61%	66%	69%	70%	73%	74%	73%	72%	70%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	44%	48%	54%	58%	64%	68%	67%	67%	67%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	35%	40%	47%	53%	61%	68%	71%	79%	79%
Cylinder Deactivation on OHV	DEACO	2%	2%	1%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	3%	3%	4%	5%	5%	5%	5%	5%	5%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	9%	12%	12%	12%	16%	12%	10%	7%	4%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	20%	20%	23%	24%	23%	22%	18%	12%	7%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	2%	2%	2%	1%	1%	1%	1%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	1%	4%	5%	5%	5%	6%	3%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	2%	3%	3%	6%	9%	17%	19%	28%	33%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3%	5%	6%	7%	5%	7%	7%	10%	12%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	1%	2%	2%	2%	5%	4%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	3%	4%	6%	7%	6%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	3%	3%	4%	4%	3%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	1%	2%	2%	3%	3%	4%	5%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	1%	1%	1%	1%	1%	2%	2%	3%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	3%	3%	1%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	1%	2%	4%	5%	6%	6%	7%	8%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	45%	32%	20%	11%	3%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	26%	26%	23%	20%	16%	14%	13%	12%	8%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	25%	37%	50%	56%	60%	59%	56%	56%
Shift Optimizer	SHFTOPT	18%	40%	54%	67%	83%	86%	83%	79%	74%
Electric Power Steering	EPS	67%	69%	73%	77%	89%	92%	95%	95%	95%
Improved Accessories - Level 1	IACC1	52%	55%	58%	64%	84%	88%	92%	94%	95%

Improved Accessories - Level 2	IACC2	28%	36%	48%	58%	69%	74%	84%	89%	89%
12V Micro-Hybrid (Stop-Start)	MHEV	7%	10%	16%	26%	33%	39%	40%	41%	37%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1*	SHEV1	3%	3%	3%	3%	3%	3%	3%	3%	3%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	1%
Strong Hybrid - Level 2*	SHEV2	0%	0%	0%	0%	0%	0%	4%	6%	10%
Plug-in Hybrid - 30 mi range*	PHEV1	0%	0%	0%	0%	0%	0%	1%	3%	4%
Plug-in Hybrid *	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range*	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range*	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range*	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range*	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	54%	60%	63%	64%	63%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	22%	35%	48%	51%	50%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	11%	14%	16%	18%	18%	18%	19%	20%	20%
Mass Reduction - Level 4	MR4	2%	4%	4%	6%	6%	7%	8%	10%	10%
Mass Reduction - Level 5	MR5	0%	2%	2%	3%	4%	4%	5%	8%	9%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	39%	54%	65%	77%	86%	88%	89%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	88%	89%	89%	90%	90%	91%	91%	91%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	41%	51%	65%	73%	84%	88%	88%	89%	89%

* DOT has not yet been able to modify the CAFE model to explicitly estimate the extent to which manufacturers might respond to the proposed technology incentives by building greater numbers of HEVs, PHEVs, and/or EVs. Increased application of such technologies could result in reduced estimated application of some other technologies (*e.g.*, diesel engines).

2% Annual Increase - Passenger Cars

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	75%	81%	81%	81%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	68%	74%	76%	77%	85%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	11%	21%	28%	37%	46%	55%	64%	68%	72%
Variable Valve Timing (VVT) - Coupled Cam Phasing on SOHC	CCPS	4%	4%	4%	4%	4%	4%	4%	4%	4%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	11%	11%	11%	11%	12%
Cylinder Deactivation on SOHC	DEACS	2%	2%	2%	2%	2%	2%	1%	1%	1%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	19%	18%	17%	17%	17%	17%	16%	16%	16%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	61%	62%	63%	63%	63%	63%	64%	64%	64%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	36%	37%	38%	39%	41%	43%	44%	45%	46%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	0%	0%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	27%	29%	30%	33%	34%	34%	37%	40%	42%
Cylinder Deactivation on OHV	DEACO	2%	2%	2%	2%	2%	2%	2%	2%	2%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	3%	2%	2%	3%	2%	2%	2%	2%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	6%	6%	6%	5%	5%	2%	2%	2%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	17%	19%	20%	20%	19%	19%	19%	16%	11%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	2%	2%	2%	1%	1%	1%	1%	0%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	1%	1%	4%	4%	7%	9%	11%	11%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	0%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	1%	1%	1%	1%	1%	1%	1%	1%	4%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3%	3%	3%	3%	4%	4%	4%	7%	10%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	0%	0%	1%	1%	2%	2%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	0%	1%	1%	1%	1%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	3%	3%	1%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	1%	3%	3%	4%	4%	4%	4%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	48%	41%	29%	23%	14%	10%	6%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	25%	25%	24%	19%	18%	17%	16%	14%	12%
High Efficiency Gearbox (Auto or DCT)	HETRANS	7%	17%	30%	42%	51%	56%	61%	68%	70%
Shift Optimizer	SHFTOPT	16%	32%	48%	59%	70%	75%	80%	87%	87%
Electric Power Steering	EPS	64%	65%	66%	68%	71%	72%	76%	79%	82%
Improved Accessories - Level 1	IACC1	50%	51%	52%	56%	57%	58%	63%	64%	65%
Improved Accessories - Level 2	IACC2	26%	30%	32%	36%	41%	44%	50%	50%	51%
12V Micro-Hybrid (Stop-Start)	MHEV	4%	4%	4%	4%	4%	4%	4%	4%	4%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	4%	3%	3%	3%	4%	4%	4%	4%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	49%	56%	56%	59%	62%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	20%	29%	38%	40%	40%	41%	44%	44%	44%
Mass Reduction - Level 3	MR3	11%	12%	14%	15%	15%	16%	18%	18%	18%
Mass Reduction - Level 4	MR4	0%	0%	0%	0%	0%	0%	1%	1%	2%
Mass Reduction - Level 5	MR5	0%	0%	0%	0%	0%	0%	0%	0%	1%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	37%	50%	64%	78%	86%	87%	88%	88%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	88%	88%	88%	89%	89%	89%	89%	90%	90%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	40%	41%	52%	60%	69%	72%	74%	79%	81%

3% Annual Increase - Passenger Cars										
Technology	**Abbr.**	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Low Friction Lubricants - Level 1	LUB1	80%	84%	89%	89%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	78%	83%	87%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	11%	26%	34%	42%	50%	58%	65%	71%	73%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	4%	5%	10%	10%	10%	10%	10%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	11%	11%	11%	11%	11%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	19%	12%	9%	6%	6%	6%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	61%	68%	71%	74%	74%	74%	76%	75%	73%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	40%	42%	46%	49%	51%	55%	56%	61%	60%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	5%	5%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	1%	1%	1%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	32%	36%	38%	44%	48%	53%	59%	66%	66%
Cylinder Deactivation on OHV	DEACO	2%	2%	2%	2%	2%	2%	2%	1%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	4%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	3%	3%	2%	3%	3%	3%	3%	3%	4%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	8%	9%	6%	6%	7%	6%	8%	9%	6%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	18%	20%	23%	23%	22%	23%	19%	17%	15%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	2%	2%	2%	1%	1%	1%	1%	0%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	2%	2%	4%	4%	4%	5%	5%	6%	6%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	1%	1%	1%	5%	7%	11%	14%	18%	19%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3%	4%	4%	6%	4%	4%	8%	11%	12%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	3%	3%	3%	3%	3%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	0%	1%	2%	2%	3%	3%	5%	4%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	1%	1%	1%	1%	1%	3%	4%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	0%	0%	0%	0%	2%	3%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	3%	3%	1%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	1%	2%	3%	4%	4%	5%	5%	5%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	46%	35%	24%	16%	7%	5%	2%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	27%	27%	25%	20%	18%	14%	13%	13%	9%
High Efficiency Gearbox (Auto or DCT)	HETRANS	7%	21%	34%	43%	52%	61%	66%	66%	69%
Shift Optimizer	SHFTOPT	16%	34%	53%	63%	74%	78%	83%	83%	84%
Electric Power Steering	EPS	66%	68%	69%	72%	78%	81%	88%	94%	95%
Improved Accessories - Level 1	IACC1	51%	53%	54%	58%	65%	69%	75%	86%	88%
Improved Accessories - Level 2	IACC2	26%	31%	36%	43%	57%	64%	72%	82%	83%
12V Micro-Hybrid (Stop-Start)	MHEV	5%	5%	9%	12%	18%	21%	25%	26%	29%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	4%	3%	3%	3%	4%	3%	3%	3%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	0%	2%	2%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	1%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	54%	60%	63%	64%	63%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	20%	33%	46%	48%	48%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	11%	14%	16%	18%	18%	18%	19%	19%	20%
Mass Reduction - Level 4	MR4	2%	3%	4%	5%	5%	6%	8%	10%	10%
Mass Reduction - Level 5	MR5	0%	0%	0%	1%	2%	2%	4%	4%	6%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	39%	54%	65%	77%	86%	88%	89%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	88%	88%	89%	89%	90%	91%	91%	91%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	42%	48%	62%	70%	81%	85%	85%	89%	89%

4% Annual Increase - Passenger Cars

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1										
Engine Friction Reduction - Level 1	EFR1	83%	88%	88%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	12%	22%	34%	41%	51%	56%	59%	62%	64%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	4%	5%	10%	10%	10%	10%	10%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	11%	11%	11%	11%	11%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	17%	15%	12%	9%	4%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	63%	64%	67%	69%	74%	75%	74%	72%	71%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	43%	48%	53%	58%	63%	69%	68%	68%	67%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	37%	43%	51%	57%	67%	74%	76%	81%	82%
Cylinder Deactivation on OHV	DEACO	2%	2%	1%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	3%	3%	4%	5%	5%	5%	5%	5%	5%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	10%	12%	12%	12%	13%	9%	7%	4%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	21%	20%	20%	21%	20%	19%	15%	11%	7%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	2%	2%	2%	2%	1%	1%	1%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	1%	3%	4%	9%	10%	10%	8%	8%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	2%	4%	5%	9%	12%	19%	21%	29%	33%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3%	5%	8%	10%	8%	9%	9%	11%	12%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	1%	1%	2%	2%	5%	4%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	1%	1%	3%	3%	3%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	3%	3%	4%	4%	3%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	1%	1%	2%	2%	3%	4%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	1%	1%	1%	1%	1%	2%	3%	4%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	4%	3%	2%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	1%	2%	4%	6%	7%	7%	8%	8%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	44%	31%	20%	12%	3%	3%	2%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	27%	27%	25%	20%	16%	13%	12%	11%	8%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	25%	37%	48%	53%	58%	57%	56%	55%
Shift Optimizer	SHFTOPT	18%	40%	52%	63%	79%	82%	79%	76%	72%
Electric Power Steering	EPS	70%	76%	88%	93%	94%	95%	95%	95%	95%
Improved Accessories - Level 1	IACC1	61%	67%	75%	86%	92%	93%	93%	94%	95%
Improved Accessories - Level 2	IACC2	35%	42%	56%	70%	79%	83%	86%	86%	87%
12V Micro-Hybrid (Stop-Start)	MHEV	9%	17%	22%	31%	36%	42%	39%	41%	37%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	3%	3%	3%	3%	3%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	3%	3%	6%	8%	11%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	1%	3%	5%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	59%	61%	64%	64%	63%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	22%	35%	48%	51%	51%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	12%	16%	18%	20%	20%	19%	19%	20%	20%
Mass Reduction - Level 4	MR4	2%	4%	5%	7%	7%	8%	8%	10%	10%
Mass Reduction - Level 5	MR5	0%	2%	2%	5%	6%	6%	7%	9%	9%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	40%	54%	65%	77%	86%	88%	89%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	88%	89%	89%	90%	90%	91%	91%	91%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	42%	51%	65%	73%	84%	88%	88%	89%	89%

5% Annual Increase - Passenger Cars

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	89%	89%	89%	89%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	83%	88%	88%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	15%	28%	34%	39%	44%	45%	48%	52%	54%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	4%	5%	10%	10%	9%	9%	9%	9%	9%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	12%	11%	12%	11%	11%	10%	10%	11%	11%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	10%	5%	4%	3%	3%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	70%	74%	73%	73%	72%	70%	70%	69%	68%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	52%	56%	60%	64%	67%	65%	65%	64%	65%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	47%	55%	64%	70%	77%	77%	81%	80%	79%
Cylinder Deactivation on OHV	DEACO	2%	2%	1%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	3%	3%	4%	5%	5%	5%	5%	5%	5%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	15%	20%	20%	19%	16%	10%	9%	2%	1%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	23%	21%	19%	20%	19%	16%	15%	12%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	2%	2%	2%	2%	2%	2%	2%	1%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	2%	3%	4%	4%	5%	4%	4%	3%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	1%	1%	1%	1%	1%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	2%	3%	7%	9%	19%	24%	24%	23%	23%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	4%	5%	9%	11%	8%	10%	10%	7%	8%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	1%	2%	3%	4%	7%	8%	6%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	1%	1%	1%	2%	3%	3%	3%	3%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	2%	3%	3%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	2%	3%	5%	7%	7%	9%	9%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	1%	1%	1%	1%	1%	1%	1%	2%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	4%	3%	1%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	2%	3%	5%	7%	8%	8%	8%	8%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	42%	29%	17%	9%	2%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	26%	27%	24%	19%	16%	14%	13%	12%	9%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	25%	37%	44%	47%	49%	46%	36%	36%
Shift Optimizer	SHFTOPT	19%	40%	58%	73%	80%	82%	77%	65%	58%
Electric Power Steering	EPS	71%	80%	85%	89%	94%	95%	95%	95%	95%
Improved Accessories - Level 1	IACC1	55%	66%	74%	80%	89%	93%	93%	94%	95%
Improved Accessories - Level 2	IACC2	31%	41%	53%	60%	70%	77%	79%	80%	80%
12V Micro-Hybrid (Stop-Start)	MHEV	20%	32%	43%	54%	65%	72%	72%	60%	53%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	3%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	1%	3%	3%	3%	3%
Strong Hybrid - Level 2	SHEV2	0%	0%	2%	2%	2%	2%	4%	14%	18%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	2%	3%	6%	9%	11%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	62%	64%	64%	64%	63%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	22%	35%	48%	51%	51%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	12%	16%	18%	21%	21%	20%	20%	20%	20%
Mass Reduction - Level 4	MR4	3%	6%	8%	10%	10%	10%	10%	10%	10%
Mass Reduction - Level 5	MR5	0%	2%	2%	5%	6%	7%	8%	10%	10%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	40%	54%	65%	76%	85%	88%	89%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	88%	89%	89%	90%	90%	91%	91%	91%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	48%	57%	70%	78%	86%	88%	88%	89%	89%

6% Annual Increase - Passenger Cars

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	89%	89%	89%	89%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	87%	88%	88%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	15%	25%	31%	34%	38%	40%	45%	49%	53%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	9%	10%	10%	10%	9%	9%	9%	9%	9%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	10%	10%	10%	10%	11%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	9%	4%	3%	3%	3%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	69%	72%	73%	71%	70%	70%	69%	69%	69%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	54%	58%	60%	62%	65%	65%	64%	65%	65%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	49%	59%	68%	71%	79%	80%	80%	80%	80%
Cylinder Deactivation on OHV	DEACO	1%	1%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	4%	4%	5%	5%	5%	5%	5%	5%	5%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	18%	19%	21%	19%	17%	12%	9%	5%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	25%	24%	23%	22%	21%	19%	16%	12%	7%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	2%	2%	2%	2%	2%	2%	2%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	2%	2%	2%	4%	7%	7%	7%	7%	5%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	2%	7%	9%	10%	11%	11%	10%	10%	13%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	4%	6%	8%	8%	9%	9%	9%	10%	13%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	1%	4%	5%	11%	12%	12%	9%	9%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	1%	1%	2%	2%	2%	1%	0%	1%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	1%	2%	2%	3%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	2%	3%	3%	5%	6%	7%	7%	7%	7%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	1%	1%	2%	2%	2%	2%	3%	3%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	5%	4%	3%	2%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	2%	3%	5%	7%	8%	8%	8%	8%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	37%	24%	14%	6%	2%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	31%	30%	27%	22%	15%	13%	12%	11%	8%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	23%	37%	43%	48%	44%	39%	34%	37%
Shift Optimizer	SHFTOPT	20%	43%	57%	69%	81%	77%	70%	58%	56%
Electric Power Steering	EPS	77%	85%	90%	92%	95%	95%	95%	95%	95%
Improved Accessories - Level 1	IACC1	65%	77%	80%	88%	92%	93%	93%	94%	95%
Improved Accessories - Level 2	IACC2	37%	49%	56%	64%	70%	73%	74%	76%	76%
12V Micro-Hybrid (Stop-Start)	MHEV	31%	46%	58%	64%	75%	73%	65%	53%	51%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	2%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	0%	3%	2%	2%	4%	9%	18%	19%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	1%	1%	8%	11%	14%	15%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	62%	64%	64%	64%	63%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	22%	35%	48%	51%	51%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	12%	16%	18%	21%	21%	20%	20%	20%	20%
Mass Reduction - Level 4	MR4	4%	7%	9%	11%	11%	10%	10%	10%	10%
Mass Reduction - Level 5	MR5	0%	2%	3%	6%	7%	8%	8%	10%	10%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	40%	54%	64%	75%	85%	88%	89%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	89%	89%	90%	90%	90%	91%	91%	91%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	54%	63%	76%	84%	88%	88%	88%	89%	89%

7% Annual Increase - Passenger Cars

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	89%	89%	89%	89%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	87%	88%	88%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	15%	27%	34%	38%	43%	46%	51%	56%	58%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	10%	10%	10%	10%	10%	10%	10%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	12%	11%	12%	11%	11%	11%	11%	12%	12%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	9%	4%	3%	3%	3%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	68%	71%	71%	70%	67%	66%	66%	66%	66%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	59%	62%	62%	64%	62%	61%	61%	62%	62%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	54%	62%	69%	72%	78%	77%	78%	78%	78%
Cylinder Deactivation on OHV	DEACO	1%	1%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	4%	4%	5%	5%	5%	5%	5%	5%	5%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	19%	18%	19%	19%	20%	18%	17%	10%	7%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	25%	24%	23%	22%	21%	19%	16%	11%	6%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	2%	3%	3%	3%	3%	2%	2%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	3%	4%	5%	6%	6%	6%	5%	4%	3%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	4%	9%	12%	13%	13%	11%	10%	16%	19%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	4%	6%	9%	9%	9%	10%	9%	8%	11%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	1%	2%	5%	5%	5%	4%	3%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	1%	1%	1%	1%	1%	1%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	0%	0%	1%	1%	1%	2%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	3%	4%	5%	6%	9%	10%	10%	10%	10%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	1%	1%	1%	1%	2%	2%	2%	2%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	5%	5%	4%	2%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	3%	4%	6%	7%	8%	8%	8%	8%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	35%	22%	11%	3%	2%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	34%	32%	29%	24%	17%	16%	15%	14%	11%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	24%	35%	41%	44%	42%	39%	35%	35%
Shift Optimizer	SHFTOPT	23%	46%	60%	73%	79%	77%	72%	63%	57%
Electric Power Steering	EPS	75%	84%	93%	94%	95%	95%	95%	95%	95%
Improved Accessories - Level 1	IACC1	64%	76%	88%	91%	92%	93%	93%	94%	95%
Improved Accessories - Level 2	IACC2	35%	47%	62%	63%	69%	72%	74%	75%	75%
12V Micro-Hybrid (Stop-Start)	MHEV	35%	51%	63%	68%	77%	73%	67%	58%	52%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	2%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	0%	2%	2%	2%	3%	4%	12%	17%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	1%	2%	9%	15%	15%	16%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	63%	64%	64%	64%	63%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	22%	35%	48%	51%	51%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	12%	16%	18%	21%	21%	20%	20%	20%	20%
Mass Reduction - Level 4	MR4	4%	7%	9%	11%	11%	10%	10%	10%	10%
Mass Reduction - Level 5	MR5	0%	3%	5%	7%	9%	10%	9%	10%	10%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	40%	54%	64%	75%	85%	88%	88%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	89%	90%	90%	90%	90%	91%	91%	91%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	55%	64%	77%	84%	88%	88%	88%	89%	89%

Max Net Benefits - Passenger Cars

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	89%	89%	89%	89%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	87%	88%	88%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	18%	22%	33%	38%	47%	49%	60%	71%	75%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	10%	10%	10%	10%	10%	10%	10%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	11%	11%	11%	11%	11%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	4%	3%	3%	3%	3%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	73%	74%	74%	74%	74%	74%	74%	74%	73%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	57%	58%	58%	60%	61%	61%	61%	64%	65%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	55%	62%	62%	64%	64%	64%	65%	69%	71%
Cylinder Deactivation on OHV	DEACO	0%	0%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	5%	5%	5%	5%	5%	5%	5%	4%	4%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	21%	24%	22%	21%	18%	17%	11%	9%	7%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	27%	27%	26%	26%	26%	25%	21%	18%	15%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	3%	3%	3%	3%	2%	2%	2%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	3%	4%	5%	7%	9%	11%	14%	13%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	1%	1%	1%	1%	1%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	3%	4%	4%	4%	5%	5%	8%	9%	13%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	5%	6%	6%	7%	7%	7%	10%	12%	14%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	1%	1%	1%	1%	1%	2%	2%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	1%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	1%	2%	2%	3%	4%	4%
Advanced Diesel - Small Displacement	ADSL_SD	3%	3%	3%	3%	3%	4%	4%	4%	4%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	0%	0%	0%	0%	0%	1%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	5%	4%	3%	2%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	1%	2%	4%	4%	5%	5%	5%	5%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	38%	25%	16%	9%	8%	7%	6%	4%	4%
8-Speed Trans (Auto or DCT)	8SPD	31%	29%	27%	22%	19%	17%	16%	16%	13%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	22%	35%	42%	47%	49%	50%	51%	54%
Shift Optimizer	SHFTOPT	23%	46%	61%	74%	77%	79%	79%	80%	79%
Electric Power Steering	EPS	82%	84%	87%	87%	87%	87%	89%	91%	92%
Improved Accessories - Level 1	IACC1	60%	66%	68%	69%	70%	71%	72%	78%	79%
Improved Accessories - Level 2	IACC2	32%	37%	40%	42%	47%	51%	56%	57%	58%
12V Micro-Hybrid (Stop-Start)	MHEV	38%	39%	39%	40%	40%	39%	38%	36%	35%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	3%	3%	3%	3%	3%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	1%	2%	3%	4%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	1%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	63%	64%	64%	64%	63%	63%	64%	63%	63%
Mass Reduction - Level 2	MR2	22%	35%	48%	51%	51%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	12%	16%	18%	20%	20%	20%	20%	20%	20%
Mass Reduction - Level 4	MR4	3%	5%	7%	8%	8%	9%	9%	9%	9%
Mass Reduction - Level 5	MR5	0%	3%	3%	4%	4%	4%	4%	4%	4%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	38%	51%	64%	77%	85%	88%	89%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	89%	89%	90%	90%	90%	90%	90%	90%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	49%	58%	67%	73%	77%	80%	80%	80%	81%

Total Cost = Total Benefits - Passenger Cars

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	89%	89%	89%	89%	89%	89%	89%	89%	89%
Engine Friction Reduction - Level 1	EFR1	87%	88%	88%	88%	88%	89%	89%	89%	89%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	18%	22%	31%	38%	52%	55%	64%	69%	71%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	10%	10%	10%	10%	7%	6%	6%	7%	7%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	8%	8%	8%	8%	8%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	4%	3%	3%	3%	3%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	73%	73%	72%	72%	71%	69%	69%	68%	67%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	62%	61%	60%	63%	66%	64%	64%	64%	64%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	58%	65%	68%	73%	78%	77%	77%	76%	76%
Cylinder Deactivation on OHV	DEACO	0%	0%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	5%	5%	5%	5%	5%	5%	5%	5%	5%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	5%	5%	5%	5%	5%	5%	5%	4%	4%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	21%	26%	25%	26%	24%	22%	18%	7%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	26%	26%	24%	22%	22%	19%	14%	10%	8%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	3%	3%	3%	3%	2%	2%	2%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	2%	2%	2%	3%	3%	2%	2%	2%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	5%	6%	10%	12%	15%	15%	17%	17%	19%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	6%	7%	8%	10%	10%	11%	14%	14%	14%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	4%	4%	4%	10%	12%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	2%	3%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	0%	0%	1%	2%	2%	3%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	3%	4%	5%	5%	8%	10%	10%	12%	12%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	0%	1%	1%	2%	2%	2%	2%	2%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	5%	4%	3%	2%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	2%	3%	5%	7%	8%	8%	8%	8%
Improved Auto. Trans. Controls/Externals	IATC	4%	1%	1%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	7%	3%	2%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	38%	25%	14%	6%	2%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	31%	29%	26%	21%	17%	15%	14%	14%	11%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	22%	35%	46%	50%	51%	49%	45%	46%
Shift Optimizer	SHFTOPT	23%	45%	59%	71%	82%	83%	80%	73%	70%
Electric Power Steering	EPS	89%	90%	91%	91%	94%	95%	95%	95%	95%
Improved Accessories - Level 1	IACC1	78%	81%	83%	84%	91%	93%	93%	94%	95%
Improved Accessories - Level 2	IACC2	42%	47%	52%	56%	63%	68%	74%	76%	76%
12V Micro-Hybrid (Stop-Start)	MHEV	42%	44%	49%	53%	63%	65%	65%	68%	65%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	3%	3%	3%	3%	3%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	1%	1%	1%	1%	1%	3%	8%	11%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	2%	5%	6%	7%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	63%	64%	64%	64%	63%	63%	64%	63%	63%

Mass Reduction - Level 2	MR2	22%	35%	48%	51%	51%	50%	51%	50%	50%
Mass Reduction - Level 3	MR3	12%	16%	18%	21%	21%	20%	20%	20%	20%
Mass Reduction - Level 4	MR4	3%	6%	8%	9%	9%	10%	10%	10%	10%
Mass Reduction - Level 5	MR5	1%	3%	3%	6%	7%	8%	8%	10%	10%
Low Rolling Resistance Tires - Level 1	ROLL1	94%	97%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	20%	39%	54%	65%	75%	85%	88%	89%	89%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	90%	90%	90%	90%	90%	91%	91%	91%	91%
Secondary Axle Disconnect	SAX	0%	0%	0%	0%	0%	0%	1%	1%	1%
Aero Drag Reduction, Level 1	AERO1	92%	97%	99%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	55%	64%	77%	84%	88%	88%	88%	89%	89%

Table V-114 Penetration Rate of New Technologies to Light Trucks, by Alternative

Preferred Alternative - Light Trucks										
Technology	**Abbr.**	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	90%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	9%	16%	29%	43%	57%	69%	86%	91%	93%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	9%	9%	10%	10%	13%	13%	13%	12%	12%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	15%	15%	14%	15%	16%	15%	15%	15%
Cylinder Deactivation on SOHC	DEACS	8%	7%	7%	7%	3%	1%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	1%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	57%	57%	57%	54%	55%	55%	56%	57%	55%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	34%	36%	42%	39%	45%	47%	51%	54%	52%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	2%	2%	1%	1%	1%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	33%	34%	44%	40%	55%	62%	66%	71%	71%
Cylinder Deactivation on OHV	DEACO	18%	19%	18%	13%	11%	11%	9%	8%	7%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	16%	17%	21%	20%	19%	18%	17%	17%	17%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	1%	1%	2%	6%	7%	7%	8%	9%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	32%	31%	38%	32%	39%	38%	33%	22%	18%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	1%	1%	4%	3%	6%	6%	5%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	1%	1%	1%	3%	3%	6%	6%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	1%	1%	1%	2%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	0%	1%	1%	0%	0%	1%	2%	3%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	0%	3%	4%	10%	14%	17%	24%	35%	39%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	0%	1%	1%	4%	6%	7%	7%	8%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	5%	6%	6%	7%	6%	8%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	1%	1%	1%	1%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	37%	27%	16%	9%	1%	0%	0%	0%	0%
6-speed DCT	DCT	11%	5%	4%	3%	3%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	40%	39%	28%	21%	8%	7%	6%	5%	1%
High Efficiency Gearbox (Auto or DCT)	HETRANS	7%	23%	42%	59%	69%	69%	70%	71%	75%
Shift Optimizer	SHFTOPT	19%	30%	45%	56%	78%	94%	95%	96%	96%
Electric Power Steering	EPS	33%	36%	46%	57%	64%	72%	77%	82%	83%
Improved Accessories - Level 1	IACC1	54%	57%	58%	66%	71%	73%	73%	78%	82%
Improved Accessories - Level 2	IACC2	20%	24%	34%	47%	59%	65%	71%	75%	80%
12V Micro-Hybrid (Stop-Start)	MHEV	1%	2%	4%	9%	11%	12%	17%	22%	23%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	2%	1%	1%	1%	1%	1%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	95%	95%	95%	98%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	39%	52%	74%	83%	91%	96%	99%	99%	100%
Mass Reduction - Level 3	MR3	17%	20%	23%	32%	42%	53%	65%	81%	94%
Mass Reduction - Level 4	MR4	1%	1%	1%	4%	10%	12%	16%	20%	39%
Mass Reduction - Level 5	MR5	0%	0%	0%	0%	0%	1%	6%	8%	23%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	30%	48%	64%	76%	88%	92%	99%	99%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	40%	43%	44%	50%	55%	62%	67%	70%	76%
Secondary Axle Disconnect	SAX	13%	18%	18%	19%	22%	24%	26%	28%	34%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	66%	71%	88%	94%	96%	100%	100%	100%	100%

2% Annual Increase - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	90%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	10%	12%	16%	17%	21%	22%	26%	33%	46%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	14%	13%	13%	13%	13%	13%	13%	13%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	15%	15%	15%	15%	15%	15%	15%	15%
Cylinder Deactivation on SOHC	DEACS	5%	5%	5%	5%	5%	4%	4%	4%	4%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	4%	3%	3%	3%	3%	3%	3%	3%	3%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	55%	55%	55%	55%	57%	57%	58%	59%	59%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	40%	41%	43%	43%	44%	45%	46%	47%	47%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	40%	41%	43%	43%	44%	46%	48%	49%	50%
Cylinder Deactivation on OHV	DEACO	18%	19%	19%	19%	18%	17%	16%	16%	16%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	16%	17%	17%	17%	16%	15%	14%	14%	14%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	2%	2%	2%	3%	2%	2%	2%	2%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	0%	0%	1%	1%	1%	0%	1%	1%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	35%	36%	37%	37%	38%	38%	38%	37%	35%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	1%	1%	1%	1%	0%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	0%	0%	0%	0%	1%	1%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	2%	2%	2%	1%	1%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	2%	2%	3%	3%	3%	4%	5%	7%	9%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	1%	1%	2%	3%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	1%	1%	1%	1%	1%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	35%	25%	14%	7%	1%	0%	0%	0%	0%
6-speed DCT	DCT	11%	8%	8%	7%	6%	4%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	42%	44%	36%	31%	20%	20%	16%	10%	3%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	16%	30%	44%	60%	66%	74%	81%	87%
Shift Optimizer	SHFTOPT	19%	35%	54%	60%	68%	73%	78%	83%	83%
Electric Power Steering	EPS	49%	50%	56%	56%	57%	57%	59%	61%	67%
Improved Accessories - Level 1	IACC1	65%	66%	68%	68%	67%	68%	67%	69%	75%
Improved Accessories - Level 2	IACC2	28%	32%	38%	39%	44%	44%	47%	50%	57%
12V Micro-Hybrid (Stop-Start)	MHEV	2%	2%	2%	2%	2%	2%	2%	2%	2%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	2%	1%	1%	1%	2%	1%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	95%	97%	98%	99%	99%	99%	99%	100%	100%
Mass Reduction - Level 2	MR2	45%	50%	66%	72%	80%	80%	87%	97%	100%
Mass Reduction - Level 3	MR3	33%	34%	36%	38%	40%	45%	53%	61%	71%
Mass Reduction - Level 4	MR4	1%	1%	1%	1%	1%	1%	2%	2%	10%
Mass Reduction - Level 5	MR5	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	30%	47%	62%	74%	85%	93%	99%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	51%	53%	54%	54%	53%	53%	53%	53%	54%
Secondary Axle Disconnect	SAX	19%	20%	20%	20%	19%	19%	19%	19%	21%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	66%	71%	89%	96%	97%	100%	100%	100%	100%

3% Annual Increase - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	90%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	12%	24%	33%	41%	48%	55%	69%	84%	88%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	14%	13%	13%	13%	13%	13%	13%	13%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	16%	15%	15%	16%	16%	16%	15%	15%
Cylinder Deactivation on SOHC	DEACS	8%	7%	5%	6%	3%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	1%	1%	1%	1%	1%	1%	1%	1%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	58%	58%	58%	58%	60%	60%	61%	61%	62%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	45%	48%	49%	50%	51%	53%	57%	59%	59%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	1%	0%	3%	3%	2%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	51%	53%	56%	56%	60%	66%	68%	73%	74%
Cylinder Deactivation on OHV	DEACO	15%	16%	16%	14%	13%	13%	12%	12%	11%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	16%	17%	21%	20%	19%	18%	18%	17%	17%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	4%	4%	4%	5%	5%	5%	5%	5%	6%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	1%	1%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	48%	48%	50%	45%	43%	41%	36%	28%	25%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	1%	1%	1%	1%	0%	0%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	0%	0%	0%	3%	3%	6%	6%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	0%	1%	1%	1%	1%	1%	2%	4%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3%	5%	7%	12%	15%	18%	24%	33%	37%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	5%	7%	8%	8%	8%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	1%	1%	1%	1%	1%	1%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	1%	1%	1%	1%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	35%	25%	14%	7%	1%	0%	0%	0%	0%
6-speed DCT	DCT	11%	5%	4%	3%	3%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	42%	39%	29%	25%	12%	12%	11%	8%	2%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	24%	44%	52%	74%	77%	78%	80%	86%
Shift Optimizer	SHFTOPT	19%	40%	56%	69%	79%	89%	96%	96%	96%
Electric Power Steering	EPS	47%	49%	60%	64%	64%	66%	71%	81%	85%
Improved Accessories - Level 1	IACC1	62%	64%	65%	67%	67%	68%	69%	78%	81%
Improved Accessories - Level 2	IACC2	25%	35%	41%	50%	52%	54%	61%	72%	80%
12V Micro-Hybrid (Stop-Start)	MHEV	3%	3%	4%	3%	4%	4%	4%	4%	4%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	2%	1%	1%	1%	1%	1%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	95%	98%	99%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	45%	59%	81%	90%	98%	99%	99%	99%	100%
Mass Reduction - Level 3	MR3	34%	39%	53%	59%	63%	67%	76%	89%	92%
Mass Reduction - Level 4	MR4	3%	3%	6%	12%	18%	19%	23%	27%	37%
Mass Reduction - Level 5	MR5	0%	0%	0%	0%	0%	1%	5%	5%	12%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	31%	47%	64%	77%	89%	93%	99%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	53%	55%	56%	56%	56%	58%	61%	66%	72%
Secondary Axle Disconnect	SAX	22%	23%	23%	22%	22%	22%	25%	27%	32%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	67%	70%	87%	93%	94%	97%	97%	100%	100%

4% Annual Increase - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	90%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	13%	24%	39%	50%	61%	67%	76%	78%	79%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	14%	13%	13%	13%	13%	13%	12%	12%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	16%	15%	15%	15%	15%	15%	15%	15%
Cylinder Deactivation on SOHC	DEACS	6%	6%	5%	5%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	1%	1%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	58%	58%	58%	59%	59%	59%	59%	59%	59%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	45%	48%	50%	50%	50%	52%	56%	57%	57%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	53%	56%	60%	61%	66%	71%	75%	76%	75%
Cylinder Deactivation on OHV	DEACO	11%	10%	3%	1%	1%	1%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	16%	17%	19%	19%	18%	17%	15%	15%	15%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	9%	10%	16%	18%	17%	17%	15%	15%	15%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	1%	1%	2%	2%	2%	2%	2%	0%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	50%	50%	49%	43%	32%	29%	23%	9%	6%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	6%	7%	9%	8%	8%	7%	4%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	1%	1%	1%	1%	1%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	2%	2%	2%	2%	6%	5%	5%	4%	4%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	1%	1%	3%	3%	5%	5%	8%	8%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	7%	8%	10%	9%	15%	19%	22%	33%	37%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	1%	2%	8%	8%	10%	12%	10%	6%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	4%	4%	7%	9%	13%	12%	15%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	0%	0%	1%	1%	1%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	1%	2%	4%	4%	5%	6%	6%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	1%	1%	2%	2%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	35%	25%	14%	7%	1%	0%	0%	0%	0%
6-speed DCT	DCT	11%	4%	4%	3%	3%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	42%	39%	27%	21%	8%	8%	6%	5%	0%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	25%	45%	55%	69%	67%	68%	65%	68%
Shift Optimizer	SHFTOPT	19%	41%	60%	77%	88%	94%	94%	91%	87%
Electric Power Steering	EPS	51%	57%	68%	72%	74%	81%	88%	92%	97%
Improved Accessories - Level 1	IACC1	65%	66%	68%	69%	70%	80%	86%	93%	97%
Improved Accessories - Level 2	IACC2	26%	39%	44%	54%	60%	74%	83%	92%	97%
12V Micro-Hybrid (Stop-Start)	MHEV	6%	12%	25%	40%	49%	51%	53%	51%	47%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	2%	1%	1%	1%	1%	1%	1%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	1%	2%	6%	9%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%

Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	95%	98%	99%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	45%	59%	82%	92%	100%	100%	100%	100%	100%
Mass Reduction - Level 3	MR3	37%	46%	69%	79%	89%	92%	96%	100%	100%
Mass Reduction - Level 4	MR4	5%	9%	17%	28%	35%	42%	46%	52%	57%
Mass Reduction - Level 5	MR5	1%	1%	1%	2%	7%	8%	14%	18%	38%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	34%	47%	64%	73%	86%	92%	99%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	56%	59%	65%	65%	73%	78%	78%	81%	84%
Secondary Axle Disconnect	SAX	23%	26%	27%	27%	27%	34%	35%	40%	43%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	67%	73%	90%	96%	97%	100%	100%	100%	100%

5% Annual Increase - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	90%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	12%	25%	37%	49%	58%	61%	68%	70%	70%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	14%	13%	13%	13%	13%	13%	12%	12%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	16%	15%	15%	15%	16%	15%	15%	15%
Cylinder Deactivation on SOHC	DEACS	3%	3%	2%	2%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	1%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	58%	55%	55%	51%	53%	50%	51%	50%	49%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	48%	52%	53%	48%	49%	47%	47%	46%	46%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	1%	1%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	61%	63%	66%	61%	65%	66%	67%	66%	65%
Cylinder Deactivation on OHV	DEACO	9%	9%	2%	1%	0%	1%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	19%	19%	19%	19%	18%	17%	17%	16%	16%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	14%	15%	19%	20%	19%	18%	18%	17%	17%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	2%	1%	2%	2%	2%	2%	2%	0%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	51%	48%	40%	33%	27%	24%	21%	15%	13%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	5%	5%	8%	8%	8%	7%	6%	6%	4%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	3%	3%	1%	2%	2%	2%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	1%	2%	2%	2%	2%	2%	2%	2%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	8%	11%	20%	20%	25%	26%	28%	25%	25%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	1%	1%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	2%	4%	5%	6%	6%	4%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	1%	4%	9%	10%	10%	11%	8%	8%	4%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	1%	1%	4%	4%	4%	4%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	3%	4%	8%	8%	9%	10%	11%	11%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	2%	2%	2%	2%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	29%	19%	9%	2%	1%	0%	0%	0%	0%
6-speed DCT	DCT	11%	4%	4%	3%	3%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	47%	40%	28%	21%	8%	7%	5%	4%	2%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	25%	46%	54%	64%	62%	58%	50%	43%
Shift Optimizer	SHFTOPT	19%	44%	64%	80%	84%	89%	87%	76%	66%
Electric Power Steering	EPS	54%	60%	75%	86%	96%	96%	96%	96%	97%
Improved Accessories - Level 1	IACC1	68%	72%	79%	86%	96%	96%	96%	96%	97%
Improved Accessories - Level 2	IACC2	28%	43%	56%	69%	82%	83%	86%	86%	90%
12V Micro-Hybrid (Stop-Start)	MHEV	29%	42%	55%	61%	71%	76%	76%	68%	59%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	1%	1%	1%	1%	1%	1%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	3%	5%	8%	19%	27%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	1%	2%	3%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	95%	98%	99%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	45%	59%	82%	92%	100%	100%	100%	100%	100%
Mass Reduction - Level 3	MR3	37%	46%	69%	79%	90%	92%	96%	100%	100%
Mass Reduction - Level 4	MR4	7%	11%	19%	34%	47%	52%	56%	60%	63%
Mass Reduction - Level 5	MR5	1%	4%	5%	7%	13%	16%	22%	29%	49%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	34%	47%	64%	73%	86%	93%	99%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	59%	63%	67%	76%	84%	84%	84%	84%	84%
Secondary Axle Disconnect	SAX	23%	28%	33%	41%	43%	43%	42%	42%	43%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	67%	73%	90%	96%	97%	100%	100%	100%	100%

6% Annual Increase - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	91%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	13%	23%	37%	44%	53%	56%	68%	73%	78%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	13%	13%	13%	12%	13%	12%	12%	12%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	15%	15%	14%	15%	15%	15%	15%	15%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	1%	1%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	57%	54%	54%	53%	53%	51%	51%	52%	51%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	49%	51%	51%	49%	49%	47%	48%	48%	48%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	66%	66%	67%	65%	66%	66%	66%	66%	66%
Cylinder Deactivation on OHV	DEACO	4%	4%	2%	1%	0%	1%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	19%	19%	19%	19%	18%	17%	16%	16%	16%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	16%	17%	19%	20%	19%	18%	17%	17%	17%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	5%	4%	4%	4%	4%	1%	1%	0%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	52%	47%	40%	38%	37%	34%	30%	24%	15%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	12%	12%	12%	13%	10%	10%	9%	9%	6%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	1%	2%	2%	1%	1%	1%	1%	1%	1%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	8%	11%	17%	17%	17%	19%	18%	13%	20%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	1%	1%	1%	1%	1%	1%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	2%	3%	3%	3%	3%	1%	1%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	1%	4%	7%	7%	8%	9%	6%	6%	4%
Advanced Diesel - Small Displacement	ADSL_SD	0%	2%	3%	4%	4%	6%	6%	7%	7%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	3%	4%	6%	7%	7%	8%	8%	8%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	2%	2%	2%	2%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	29%	19%	8%	1%	0%	0%	0%	0%	0%
6-speed DCT	DCT	8%	2%	1%	0%	0%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	48%	40%	28%	23%	12%	12%	10%	9%	5%
High Efficiency Gearbox (Auto or DCT)	HETRANS	11%	27%	46%	54%	65%	62%	54%	43%	40%
Shift Optimizer	SHFTOPT	19%	43%	68%	85%	88%	87%	78%	67%	60%
Electric Power Steering	EPS	62%	67%	84%	94%	96%	96%	96%	96%	97%
Improved Accessories - Level 1	IACC1	72%	75%	85%	95%	96%	96%	96%	96%	97%
Improved Accessories - Level 2	IACC2	33%	46%	59%	70%	77%	80%	82%	82%	85%
12V Micro-Hybrid (Stop-Start)	MHEV	43%	56%	70%	74%	81%	83%	74%	61%	53%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	1%	1%	0%	0%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	1%	1%	1%	4%	7%	14%	26%	33%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	2%	3%	3%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	96%	99%	99%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	45%	59%	82%	92%	100%	100%	100%	100%	100%
Mass Reduction - Level 3	MR3	38%	53%	76%	85%	95%	98%	98%	100%	100%
Mass Reduction - Level 4	MR4	11%	15%	20%	35%	48%	50%	54%	57%	63%
Mass Reduction - Level 5	MR5	2%	6%	8%	19%	32%	38%	43%	48%	58%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	34%	47%	64%	74%	87%	92%	98%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	70%	72%	78%	84%	84%	84%	84%	84%	84%
Secondary Axle Disconnect	SAX	33%	36%	39%	43%	43%	43%	42%	42%	43%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	69%	74%	90%	96%	97%	100%	100%	100%	100%

7% Annual Increase - Light Trucks										
Technology	**Abbr.**	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	91%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	12%	27%	33%	42%	44%	48%	53%	58%	63%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	13%	13%	13%	12%	13%	12%	12%	12%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	15%	15%	14%	15%	15%	15%	15%	15%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	0%	0%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	57%	54%	53%	53%	53%	54%	55%	55%	55%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	51%	51%	51%	50%	50%	51%	52%	52%	52%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	66%	67%	68%	67%	68%	70%	71%	71%	71%
Cylinder Deactivation on OHV	DEACO	4%	4%	2%	1%	0%	1%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	19%	19%	19%	19%	18%	17%	16%	16%	16%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	17%	17%	19%	20%	19%	18%	17%	17%	17%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	5%	4%	4%	4%	4%	4%	4%	3%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	49%	44%	36%	35%	34%	32%	30%	22%	12%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	13%	13%	15%	15%	13%	11%	10%	10%	5%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	1%	2%	3%	1%	1%	1%	1%	1%	1%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	11%	14%	21%	23%	18%	20%	18%	12%	20%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	1%	1%	1%	1%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	1%	1%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	4%	3%	4%	5%	6%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	3%	3%	4%	5%	6%	4%	4%	4%
Advanced Diesel - Small Displacement	ADSL_SD	0%	2%	2%	3%	4%	4%	4%	4%	4%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	4%	5%	5%	6%	6%	6%	6%	6%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	2%	2%	2%	2%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	29%	19%	8%	1%	0%	0%	0%	0%	0%
6-speed DCT	DCT	8%	2%	1%	0%	0%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	48%	40%	28%	22%	12%	12%	10%	9%	5%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	26%	46%	54%	63%	61%	54%	42%	41%
Shift Optimizer	SHFTOPT	18%	42%	67%	83%	86%	85%	77%	66%	60%
Electric Power Steering	EPS	68%	74%	92%	95%	96%	96%	96%	96%	97%
Improved Accessories - Level 1	IACC1	81%	82%	96%	96%	96%	96%	96%	96%	97%
Improved Accessories - Level 2	IACC2	39%	50%	65%	74%	76%	80%	84%	84%	87%
12V Micro-Hybrid (Stop-Start)	MHEV	50%	59%	73%	77%	84%	82%	73%	59%	53%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	1%	1%	0%	0%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	1%	1%	2%	2%	6%	8%	15%	25%	32%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	2%	5%	5%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	96%	99%	99%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	45%	59%	82%	92%	100%	100%	100%	100%	100%
Mass Reduction - Level 3	MR3	38%	53%	76%	86%	96%	98%	98%	100%	100%
Mass Reduction - Level 4	MR4	11%	21%	33%	48%	61%	63%	63%	63%	63%
Mass Reduction - Level 5	MR5	2%	6%	17%	31%	44%	50%	54%	58%	60%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	34%	47%	64%	74%	86%	91%	98%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	83%	83%	84%	84%	84%	84%	84%	84%	84%
Secondary Axle Disconnect	SAX	37%	39%	43%	43%	43%	43%	42%	42%	43%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	69%	74%	90%	96%	97%	100%	100%	100%	100%

Max Net Benefits - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	91%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	13%	26%	33%	44%	53%	59%	67%	73%	78%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	13%	13%	12%	12%	12%	12%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	15%	14%	14%	15%	15%	15%	13%	13%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	0%	0%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	57%	54%	53%	53%	55%	55%	56%	56%	56%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	54%	51%	51%	51%	52%	53%	54%	54%	54%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	73%	69%	67%	67%	69%	71%	72%	70%	70%
Cylinder Deactivation on OHV	DEACO	4%	4%	2%	1%	0%	1%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	19%	19%	19%	19%	18%	17%	17%	16%	16%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	17%	17%	19%	20%	19%	18%	18%	17%	17%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	9%	7%	5%	5%	5%	3%	2%	2%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	44%	40%	39%	38%	38%	35%	33%	20%	11%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	17%	13%	14%	15%	15%	14%	12%	12%	7%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	1%	1%	1%	1%	1%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	1%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	1%	1%	1%	1%	1%	1%	1%	1%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	17%	19%	20%	20%	16%	17%	16%	15%	21%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	1%	1%	1%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	3%	3%	4%	4%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	5%	5%	6%	13%	14%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	3%	3%	5%	5%	6%	4%	4%	4%
Advanced Diesel - Small Displacement	ADSL_SD	0%	1%	2%	3%	3%	3%	3%	3%	3%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	3%	4%	4%	4%	4%	4%	6%	6%
Advanced Diesel - Large Displacement	ADSL_LD	1%	1%	1%	1%	1%	1%	1%	1%	1%
6-Speed Manual/Improved Internals	6MAN	2%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	2%	2%	2%	2%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	33%	23%	12%	6%	0%	0%	0%	0%	0%
6-speed DCT	DCT	8%	2%	1%	0%	0%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	43%	40%	28%	23%	13%	13%	11%	10%	6%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	26%	43%	51%	57%	56%	50%	45%	41%
Shift Optimizer	SHFTOPT	19%	40%	62%	80%	90%	91%	83%	78%	68%
Electric Power Steering	EPS	78%	83%	92%	95%	96%	96%	96%	96%	97%
Improved Accessories - Level 1	IACC1	95%	95%	96%	96%	96%	96%	96%	96%	97%
Improved Accessories - Level 2	IACC2	46%	52%	56%	63%	64%	69%	74%	75%	79%
12V Micro-Hybrid (Stop-Start)	MHEV	66%	72%	78%	77%	80%	84%	77%	71%	62%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	1%	1%	0%	0%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	1%	1%	2%	3%	4%	4%	10%	16%	24%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	2%	3%	4%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	96%	99%	99%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	45%	59%	82%	92%	100%	100%	100%	100%	100%
Mass Reduction - Level 3	MR3	38%	53%	76%	86%	96%	98%	98%	100%	100%
Mass Reduction - Level 4	MR4	12%	18%	28%	43%	52%	52%	54%	59%	59%
Mass Reduction - Level 5	MR5	2%	6%	17%	27%	34%	40%	44%	49%	53%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	33%	47%	64%	75%	87%	91%	98%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	83%	83%	84%	84%	84%	84%	84%	84%	84%
Secondary Axle Disconnect	SAX	44%	44%	43%	43%	43%	43%	42%	42%	43%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	69%	74%	90%	96%	97%	100%	100%	100%	100%

Total Cost = Total Benefits - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	91%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	13%	26%	33%	44%	49%	55%	66%	71%	76%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	13%	13%	13%	13%	13%	13%	11%	11%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	17%	16%	16%	15%	15%	15%	15%	13%	13%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	0%	0%	0%	0%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	57%	53%	53%	53%	54%	55%	55%	55%	55%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	54%	50%	50%	51%	52%	53%	53%	53%	54%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	73%	69%	67%	67%	69%	71%	71%	70%	70%
Cylinder Deactivation on OHV	DEACO	4%	4%	2%	1%	0%	1%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	19%	19%	19%	19%	18%	17%	17%	16%	16%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	17%	17%	19%	20%	19%	18%	18%	17%	17%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	9%	6%	4%	4%	4%	2%	2%	2%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	46%	41%	41%	40%	39%	38%	34%	21%	12%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	17%	13%	14%	15%	15%	14%	12%	12%	7%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	1%	1%	1%	1%	1%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	1%	1%	1%	1%	1%	1%	1%	1%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	15%	17%	18%	18%	13%	15%	14%	13%	21%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	1%	1%	1%	1%	1%	1%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	3%	3%	3%	3%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	5%	5%	6%	8%	9%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	3%	3%	5%	5%	6%	7%	7%	7%
Advanced Diesel - Small Displacement	ADSL_SD	0%	2%	3%	3%	3%	3%	3%	3%	3%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	3%	4%	4%	4%	4%	4%	6%	6%
Advanced Diesel - Large Displacement	ADSL_LD	1%	1%	1%	1%	1%	1%	1%	1%	1%
6-Speed Manual/Improved Internals	6MAN	2%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	2%	2%	2%	2%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	33%	23%	12%	6%	0%	0%	0%	0%	0%
6-speed DCT	DCT	8%	2%	1%	0%	0%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	43%	40%	28%	23%	13%	12%	11%	10%	6%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	26%	43%	51%	63%	62%	59%	50%	48%
Shift Optimizer	SHFTOPT	19%	40%	66%	81%	90%	92%	86%	74%	67%
Electric Power Steering	EPS	78%	80%	89%	92%	92%	93%	96%	96%	97%
Improved Accessories - Level 1	IACC1	95%	95%	96%	96%	96%	96%	96%	96%	97%
Improved Accessories - Level 2	IACC2	46%	52%	55%	60%	63%	68%	75%	81%	82%
12V Micro-Hybrid (Stop-Start)	MHEV	75%	75%	77%	76%	79%	83%	78%	68%	61%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	1%	1%	0%	0%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	1%	1%	1%	3%	3%	3%	8%	19%	24%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	3%	3%	4%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	96%	99%	99%	100%	100%	100%	100%	100%	100%

Mass Reduction - Level 2	MR2	45%	59%	82%	92%	100%	100%	100%	100%	100%
Mass Reduction - Level 3	MR3	38%	53%	76%	86%	94%	98%	98%	100%	100%
Mass Reduction - Level 4	MR4	12%	19%	30%	45%	54%	54%	58%	59%	59%
Mass Reduction - Level 5	MR5	2%	6%	17%	25%	31%	37%	42%	46%	54%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	33%	47%	64%	75%	87%	91%	98%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	83%	83%	84%	84%	84%	84%	84%	84%	84%
Secondary Axle Disconnect	SAX	44%	44%	43%	43%	43%	43%	42%	42%	43%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	69%	74%	90%	96%	97%	100%	100%	100%	100%

Table V-115. Penetration Rate of New Technologies to Combined Fleet, by Alternative

Preferred Alternative - Combined

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	86%	86%	85%	85%	85%	85%	85%	85%
Engine Friction Reduction - Level 1	EFR1	84%	87%	89%	89%	89%	89%	89%	89%	90%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	11%	20%	32%	42%	55%	62%	70%	76%	77%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	8%	8%	10%	10%	11%	11%	11%	11%	11%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	13%	13%	13%	13%	13%	13%	13%	13%	12%
Cylinder Deactivation on SOHC	DEACS	4%	3%	3%	3%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	12%	9%	6%	5%	3%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	60%	63%	65%	64%	67%	67%	67%	67%	65%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	40%	44%	50%	51%	57%	61%	62%	63%	62%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	34%	38%	46%	48%	59%	66%	69%	76%	76%
Cylinder Deactivation on OHV	DEACO	8%	8%	7%	5%	4%	4%	3%	3%	2%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	9%	9%	11%	10%	10%	9%	9%	9%	9%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	2%	2%	3%	5%	6%	6%	6%	6%	6%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	6%	7%	8%	8%	10%	8%	6%	5%	3%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	24%	24%	28%	27%	29%	28%	23%	15%	11%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	1%	1%	2%	2%	2%	2%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	1%	3%	3%	3%	5%	5%	4%	4%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	0%	0%	0%	0%	0%	1%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	1%	2%	2%	4%	6%	11%	13%	19%	23%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	2%	4%	5%	8%	8%	10%	12%	19%	21%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	1%	1%	1%	2%	3%	2%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	2%	3%	4%	5%	5%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	3%	4%	5%	5%	5%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	1%	1%	2%	2%	2%	3%	3%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	1%	1%	2%	3%	3%	3%	3%	5%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	3%	2%	2%	1%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	1%	2%	3%	4%	4%	5%	6%	6%
Improved Auto. Trans. Controls/Externals	IATC	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	18%	12%	7%	3%	0%	0%	0%	0%	0%
6-speed DCT	DCT	33%	22%	14%	8%	3%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	31%	31%	25%	20%	13%	12%	11%	10%	6%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	24%	39%	53%	60%	63%	63%	61%	62%
Shift Optimizer	SHFTOPT	19%	36%	51%	63%	82%	89%	87%	85%	82%
Electric Power Steering	EPS	54%	57%	63%	70%	80%	85%	89%	91%	91%
Improved Accessories - Level 1	IACC1	53%	56%	58%	65%	79%	83%	86%	89%	91%
Improved Accessories - Level 2	IACC2	25%	32%	43%	54%	65%	71%	79%	84%	86%
12V Micro-Hybrid (Stop-Start)	MHEV	5%	7%	12%	20%	26%	29%	33%	35%	33%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	3%	3%	3%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	3%	4%	6%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	1%	2%	3%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	69%	73%	75%	76%	76%	76%	76%	76%	75%
Mass Reduction - Level 2	MR2	29%	41%	57%	62%	65%	66%	67%	67%	67%
Mass Reduction - Level 3	MR3	13%	16%	18%	23%	26%	30%	34%	40%	45%
Mass Reduction - Level 4	MR4	2%	3%	3%	5%	8%	9%	11%	14%	20%
Mass Reduction - Level 5	MR5	0%	1%	1%	2%	3%	3%	5%	8%	14%
Low Rolling Resistance Tires - Level 1	ROLL1	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	18%	36%	52%	64%	76%	87%	89%	92%	92%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	71%	72%	73%	76%	78%	81%	83%	84%	86%
Secondary Axle Disconnect	SAX	5%	7%	7%	7%	8%	8%	9%	10%	12%
Aero Drag Reduction, Level 1	AERO1	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	50%	58%	73%	80%	88%	92%	92%	92%	92%

2% Annual Increase - Combined										
Technology	**Abbr.**	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Low Friction Lubricants - Level 1	LUB1	78%	81%	80%	80%	85%	85%	85%	85%	85%
Engine Friction Reduction - Level 1	EFR1	76%	80%	82%	82%	87%	89%	89%	89%	90%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	11%	18%	24%	30%	37%	43%	51%	56%	63%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	8%	8%	8%	7%	7%	7%	7%	7%	7%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	13%	12%	12%	12%	12%	12%	12%	12%	13%
Cylinder Deactivation on SOHC	DEACS	3%	3%	3%	3%	3%	3%	2%	2%	2%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	14%	12%	12%	12%	12%	12%	12%	12%	12%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	58%	60%	60%	60%	61%	61%	62%	62%	62%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	37%	39%	40%	41%	42%	43%	45%	46%	47%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	32%	34%	35%	37%	38%	38%	40%	43%	45%
Cylinder Deactivation on OHV	DEACO	8%	8%	8%	8%	8%	7%	7%	7%	7%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	9%	9%	9%	9%	9%	8%	8%	8%	8%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	2%	2%	2%	3%	2%	2%	2%	2%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	4%	4%	4%	3%	4%	2%	2%	2%	1%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	24%	25%	26%	26%	26%	26%	25%	23%	19%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	1%	1%	1%	1%	1%	0%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	1%	1%	3%	3%	5%	6%	8%	8%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	0%	0%	0%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	0%	0%	0%	0%	0%	0%	1%	3%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	2%	3%	3%	3%	3%	4%	5%	7%	10%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	0%	1%	1%	1%	2%	2%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	0%	0%	0%	0%	1%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	2%	2%	2%	1%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	1%	2%	3%	3%	3%	3%	3%
Improved Auto. Trans. Controls/Externals	IATC	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	17%	11%	6%	3%	0%	0%	0%	0%	0%
6-speed DCT	DCT	34%	29%	21%	17%	11%	8%	4%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	31%	32%	28%	24%	19%	18%	16%	13%	9%
High Efficiency Gearbox (Auto or DCT)	HETRANS	7%	17%	30%	42%	54%	59%	65%	72%	76%
Shift Optimizer	SHFTOPT	17%	33%	50%	59%	69%	74%	79%	86%	86%
Electric Power Steering	EPS	59%	60%	63%	64%	66%	67%	70%	73%	77%
Improved Accessories - Level 1	IACC1	55%	56%	58%	60%	61%	61%	64%	66%	68%
Improved Accessories - Level 2	IACC2	27%	30%	34%	37%	42%	44%	49%	50%	53%
12V Micro-Hybrid (Stop-Start)	MHEV	3%	3%	3%	3%	3%	3%	3%	3%	3%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	3%	3%	3%	3%	3%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	66%	71%	71%	73%	75%	76%	76%	76%	75%
Mass Reduction - Level 2	MR2	29%	37%	48%	52%	54%	54%	59%	61%	62%
Mass Reduction - Level 3	MR3	19%	20%	22%	23%	24%	26%	30%	32%	36%
Mass Reduction - Level 4	MR4	1%	1%	1%	1%	1%	1%	1%	1%	5%
Mass Reduction - Level 5	MR5	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Rolling Resistance Tires - Level 1	ROLL1	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	18%	35%	49%	63%	77%	86%	89%	92%	92%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	74%	75%	76%	76%	76%	77%	77%	77%	78%
Secondary Axle Disconnect	SAX	7%	7%	7%	7%	7%	7%	7%	7%	8%
Aero Drag Reduction, Level 1	AERO1	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	49%	52%	65%	72%	78%	82%	83%	86%	88%

3% Annual Increase - Light Trucks

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	81%	80%	79%	79%	78%	78%	77%	77%	77%
Engine Friction Reduction - Level 1	EFR1	90%	90%	91%	91%	91%	91%	91%	91%	91%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	12%	24%	33%	41%	48%	55%	69%	84%	88%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	14%	13%	13%	13%	13%	13%	13%	13%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	16%	16%	15%	15%	16%	16%	16%	15%	15%
Cylinder Deactivation on SOHC	DEACS	8%	7%	5%	6%	3%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	1%	1%	1%	1%	1%	1%	1%	1%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	58%	58%	58%	58%	60%	60%	61%	61%	62%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	45%	48%	49%	50%	51%	53%	57%	59%	59%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	1%	0%	3%	3%	2%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	51%	53%	56%	56%	60%	66%	68%	73%	74%
Cylinder Deactivation on OHV	DEACO	15%	16%	16%	14%	13%	13%	12%	12%	11%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	16%	17%	21%	20%	19%	18%	18%	17%	17%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	4%	4%	4%	5%	5%	5%	5%	5%	6%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	1%	1%	0%	0%	0%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	48%	48%	50%	45%	43%	41%	36%	28%	25%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	1%	1%	1%	1%	0%	0%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	0%	0%	0%	0%	0%	3%	3%	6%	6%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	0%	1%	1%	1%	1%	1%	2%	4%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	3%	5%	7%	12%	15%	18%	24%	33%	37%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	5%	7%	8%	8%	8%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	0%	0%	1%	1%	1%	1%	1%	1%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	1%	1%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	0%	1%	1%	1%	1%	1%	2%	2%	2%
Improved Auto. Trans. Controls/Externals	IATC	14%	8%	6%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	35%	25%	14%	7%	1%	0%	0%	0%	0%
6-speed DCT	DCT	11%	5%	4%	3%	3%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	42%	39%	29%	25%	12%	12%	11%	8%	2%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	24%	44%	52%	74%	77%	78%	80%	86%
Shift Optimizer	SHFTOPT	19%	40%	56%	69%	79%	89%	96%	96%	96%
Electric Power Steering	EPS	47%	49%	60%	64%	64%	66%	71%	81%	85%
Improved Accessories - Level 1	IACC1	62%	64%	65%	67%	67%	68%	69%	78%	81%
Improved Accessories - Level 2	IACC2	25%	35%	41%	50%	52%	54%	61%	72%	80%
12V Micro-Hybrid (Stop-Start)	MHEV	3%	3%	4%	3%	4%	4%	4%	4%	4%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	2%	2%	1%	1%	1%	1%	1%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	95%	98%	99%	100%	100%	100%	100%	100%	100%
Mass Reduction - Level 2	MR2	45%	59%	81%	90%	98%	99%	99%	99%	100%
Mass Reduction - Level 3	MR3	34%	39%	53%	59%	63%	67%	76%	89%	92%
Mass Reduction - Level 4	MR4	3%	3%	6%	12%	18%	19%	23%	27%	37%
Mass Reduction - Level 5	MR5	0%	0%	0%	0%	0%	1%	5%	5%	12%
Low Rolling Resistance Tires - Level 1	ROLL1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	15%	31%	47%	64%	77%	89%	93%	99%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	53%	55%	56%	56%	56%	58%	61%	66%	72%
Secondary Axle Disconnect	SAX	22%	23%	23%	22%	22%	22%	25%	27%	32%
Aero Drag Reduction, Level 1	AERO1	100%	100%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	67%	70%	87%	93%	94%	97%	97%	100%	100%

4% Annual Increase - Combined										
Technology	**Abbr.**	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Low Friction Lubricants - Level 1	LUB1	85%	86%	86%	85%	85%	85%	85%	85%	85%
Engine Friction Reduction - Level 1	EFR1	85%	89%	89%	89%	89%	89%	89%	89%	90%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	12%	23%	36%	44%	55%	60%	65%	68%	69%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	8%	8%	11%	11%	11%	11%	11%	11%	11%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	13%	13%	13%	13%	13%	13%	12%	12%	12%
Cylinder Deactivation on SOHC	DEACS	4%	3%	3%	2%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	11%	10%	8%	6%	3%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	61%	62%	64%	65%	69%	70%	69%	68%	67%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	44%	48%	52%	55%	59%	63%	64%	64%	64%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	43%	47%	54%	59%	67%	73%	76%	79%	80%
Cylinder Deactivation on OHV	DEACO	5%	5%	2%	1%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	9%	9%	10%	10%	9%	9%	8%	8%	8%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	5%	5%	8%	9%	9%	9%	8%	8%	8%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	7%	8%	9%	8%	9%	6%	5%	3%	1%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	31%	31%	30%	28%	24%	22%	18%	10%	7%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	1%	1%	3%	4%	4%	3%	3%	3%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	1%	2%	3%	6%	7%	7%	6%	5%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	2%	2%	2%	2%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	1%	3%	4%	7%	9%	14%	15%	22%	25%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	5%	7%	9%	10%	10%	13%	14%	19%	20%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	1%	1%	1%	2%	3%	3%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	1%	3%	4%	4%	6%	5%	4%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	2%	3%	5%	5%	7%	7%	7%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	0%	1%	1%	1%	2%	2%	3%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	1%	1%	1%	2%	2%	3%	4%	5%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	3%	3%	2%	1%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	1%	2%	3%	4%	5%	5%	6%	6%
Improved Auto. Trans. Controls/Externals	IATC	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	17%	11%	6%	3%	0%	0%	0%	0%	0%
6-speed DCT	DCT	32%	21%	14%	9%	3%	2%	1%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	33%	31%	26%	20%	13%	11%	10%	9%	5%
High Efficiency Gearbox (Auto or DCT)	HETRANS	8%	25%	40%	51%	59%	61%	61%	59%	59%
Shift Optimizer	SHFTOPT	19%	40%	55%	68%	82%	86%	84%	81%	77%
Electric Power Steering	EPS	63%	69%	81%	85%	87%	90%	92%	94%	96%
Improved Accessories - Level 1	IACC1	63%	67%	73%	80%	84%	88%	91%	94%	96%
Improved Accessories - Level 2	IACC2	32%	41%	52%	64%	73%	80%	85%	88%	90%
12V Micro-Hybrid (Stop-Start)	MHEV	8%	15%	23%	34%	41%	45%	44%	45%	40%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	3%	3%	3%	3%	3%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	0%	0%	0%	0%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	0%	0%	0%	2%	2%	5%	7%	10%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	1%	2%	4%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	73%	74%	76%	76%	76%	76%	76%	76%	75%
Mass Reduction - Level 2	MR2	30%	44%	60%	65%	68%	68%	68%	67%	67%
Mass Reduction - Level 3	MR3	21%	27%	36%	41%	44%	45%	46%	47%	47%
Mass Reduction - Level 4	MR4	3%	6%	9%	14%	17%	20%	21%	24%	26%
Mass Reduction - Level 5	MR5	0%	2%	2%	4%	6%	7%	9%	12%	18%
Low Rolling Resistance Tires - Level 1	ROLL1	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	18%	37%	51%	65%	75%	86%	89%	92%	92%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	76%	78%	81%	81%	84%	86%	87%	88%	89%
Secondary Axle Disconnect	SAX	9%	9%	10%	10%	10%	12%	13%	14%	15%
Aero Drag Reduction, Level 1	AERO1	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	51%	59%	74%	81%	89%	92%	92%	92%	92%

5% Annual Increase - Combined

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	86%	86%	86%	85%	85%	85%	85%	85%	85%
Engine Friction Reduction - Level 1	EFR1	86%	89%	89%	89%	89%	89%	89%	89%	90%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	14%	27%	35%	42%	49%	50%	55%	58%	59%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	8%	8%	11%	11%	10%	10%	10%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	13%	13%	13%	13%	12%	12%	12%	12%	12%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	0%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	6%	3%	3%	2%	2%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	66%	67%	67%	66%	65%	63%	63%	62%	62%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	51%	55%	57%	58%	60%	59%	59%	58%	58%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	1%	1%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	52%	58%	65%	66%	73%	73%	76%	75%	75%
Cylinder Deactivation on OHV	DEACO	5%	5%	2%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	10%	10%	10%	10%	10%	9%	9%	9%	8%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	7%	7%	9%	10%	10%	9%	9%	9%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	10%	13%	13%	13%	11%	7%	6%	2%	1%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	33%	31%	26%	25%	22%	19%	17%	13%	10%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	3%	3%	5%	4%	4%	4%	3%	3%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	3%	3%	3%	3%	4%	3%	2%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	1%	1%	1%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	1%	2%	5%	7%	13%	16%	16%	16%	16%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	5%	7%	13%	14%	14%	16%	16%	13%	14%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	1%	2%	2%	3%	5%	5%	4%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	1%	1%	1%	3%	3%	4%	4%	4%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	1%	2%	4%	5%	5%	6%	5%	5%	4%
Advanced Diesel - Small Displacement	ADSL_SD	0%	0%	1%	2%	4%	6%	6%	7%	7%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	2%	2%	3%	4%	4%	4%	5%	5%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	3%	3%	2%	1%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	2%	2%	4%	5%	6%	6%	6%	6%
Improved Auto. Trans. Controls/Externals	IATC	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	15%	9%	4%	1%	0%	0%	0%	0%	0%
6-speed DCT	DCT	31%	20%	12%	7%	2%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	34%	31%	25%	20%	13%	12%	10%	9%	6%
High Efficiency Gearbox (Auto or DCT)	HETRANS	9%	25%	40%	47%	53%	54%	50%	40%	38%
Shift Optimizer	SHFTOPT	19%	41%	60%	75%	82%	84%	81%	68%	61%
Electric Power Steering	EPS	65%	73%	81%	88%	95%	95%	95%	95%	96%
Improved Accessories - Level 1	IACC1	60%	68%	76%	82%	91%	94%	94%	95%	96%
Improved Accessories - Level 2	IACC2	30%	42%	54%	63%	74%	79%	81%	82%	83%
12V Micro-Hybrid (Stop-Start)	MHEV	23%	36%	47%	57%	67%	74%	73%	63%	55%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	2%	2%	2%	1%	1%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	1%	1%	2%	2%	3%	3%
Strong Hybrid - Level 2	SHEV2	0%	0%	1%	1%	2%	3%	5%	15%	21%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	1%	2%	5%	7%	9%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	74%	76%	76%	76%	76%	76%	76%	76%	75%
Mass Reduction - Level 2	MR2	30%	44%	60%	65%	68%	68%	68%	67%	67%
Mass Reduction - Level 3	MR3	21%	27%	37%	41%	45%	45%	46%	47%	47%
Mass Reduction - Level 4	MR4	4%	8%	12%	18%	23%	25%	26%	27%	28%
Mass Reduction - Level 5	MR5	0%	3%	3%	6%	9%	10%	13%	16%	23%
Low Rolling Resistance Tires - Level 1	ROLL1	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	18%	37%	51%	65%	75%	86%	89%	92%	92%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	78%	80%	81%	85%	88%	88%	89%	89%	89%
Secondary Axle Disconnect	SAX	9%	10%	12%	14%	15%	15%	15%	15%	15%
Aero Drag Reduction, Level 1	AERO1	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	55%	63%	77%	84%	90%	92%	92%	92%	92%

6% Annual Increase - Combined

Low Friction Lubricants - Level 1	LUB1	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Engine Friction Reduction - Level 1	EFR1	86%	86%	86%	85%	85%	85%	85%	85%	85%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	88%	89%	89%	89%	89%	89%	89%	89%	90%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	14%	24%	33%	37%	43%	46%	53%	57%	61%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	11%	11%	11%	11%	10%	10%	10%	10%	10%
Cylinder Deactivation on SOHC	DEACS	13%	13%	13%	12%	12%	12%	12%	12%	12%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	2%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	6%	3%	2%	2%	2%	2%	2%	2%	2%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	65%	66%	67%	64%	64%	63%	63%	63%	63%
Continuously Variable Valve Lift (CVVL)	CVVL	52%	56%	57%	57%	59%	59%	59%	59%	60%
Cylinder Deactivation on DOHC	DEACD	3%	3%	3%	3%	3%	3%	3%	3%	3%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	1%	1%	1%	1%	1%	0%	0%	0%	0%
Cylinder Deactivation on OHV	DEACO	55%	61%	68%	69%	75%	75%	75%	75%	75%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	2%	2%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	10%	10%	10%	10%	9%	9%	9%	8%	8%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	8%	9%	10%	10%	10%	9%	9%	9%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	13%	14%	15%	14%	12%	8%	6%	3%	2%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	35%	32%	29%	28%	27%	24%	21%	16%	9%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	6%	6%	6%	6%	5%	5%	4%	4%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	1%	1%	1%	3%	4%	5%	4%	5%	4%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	1%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	2%	5%	7%	7%	7%	7%	7%	7%	9%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	6%	8%	11%	11%	12%	12%	12%	11%	15%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	1%	2%	3%	7%	8%	8%	6%	6%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	2%	2%	2%	2%	1%	1%	1%
Advanced Diesel - Small Displacement	ADSL_SD	0%	2%	3%	3%	4%	4%	4%	4%	3%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	2%	3%	5%	6%	7%	7%	7%	7%
Advanced Diesel - Large Displacement	ADSL_LD	0%	2%	2%	3%	4%	4%	4%	4%	4%
6-Speed Manual/Improved Internals	6MAN	0%	0%	0%	0%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	3%	3%	2%	1%	0%	0%	0%	0%	0%
Improved Auto. Trans. Controls/Externals	IATC	1%	2%	3%	4%	5%	6%	6%	6%	6%
6-Speed Trans with Improved Internals (Auto)	NAUTO	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-speed DCT	DCT	15%	9%	4%	1%	0%	0%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	27%	16%	9%	4%	1%	1%	0%	0%	0%
High Efficiency Gearbox (Auto or DCT)	HETRANS	37%	34%	27%	22%	14%	13%	12%	11%	7%
Shift Optimizer	SHFTOPT	10%	25%	40%	47%	54%	51%	44%	37%	38%
Electric Power Steering	EPS	20%	43%	61%	75%	83%	80%	73%	61%	57%
Improved Accessories - Level 1	IACC1	71%	79%	88%	93%	95%	95%	95%	95%	96%
Improved Accessories - Level 2	IACC2	67%	76%	82%	90%	93%	94%	94%	95%	96%
12V Micro-Hybrid (Stop-Start)	MHEV	36%	48%	57%	66%	73%	75%	77%	78%	79%
Integrated Starter Generator	ISG	35%	50%	62%	68%	77%	77%	68%	56%	52%
Strong Hybrid - Level 1	SHEV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	3%	3%	2%	2%	1%	0%	0%	0%	0%
Strong Hybrid - Level 2	SHEV2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	2%	2%	3%	5%	11%	20%	24%
Plug-in Hybrid	PHEV2	0%	0%	0%	1%	1%	5%	8%	10%	11%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 2	MR2	75%	76%	76%	76%	76%	76%	76%	76%	75%
Mass Reduction - Level 3	MR3	30%	44%	60%	65%	68%	68%	68%	67%	67%
Mass Reduction - Level 4	MR4	22%	30%	39%	44%	47%	47%	47%	47%	47%
Mass Reduction - Level 5	MR5	6%	10%	13%	19%	24%	24%	25%	26%	28%
Low Rolling Resistance Tires - Level 1	ROLL1	1%	4%	4%	10%	15%	18%	20%	23%	26%
Low Rolling Resistance Tires - Level 2	ROLL2	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 3	ROLL3	18%	37%	51%	64%	75%	86%	89%	92%	92%
Low Drag Brakes	LDB	0%	0%	0%	0%	0%	0%	0%	0%	0%
Secondary Axle Disconnect	SAX	82%	83%	85%	88%	88%	88%	89%	89%	89%
Aero Drag Reduction, Level 1	AERO1	12%	13%	14%	15%	15%	15%	15%	15%	15%
Aero Drag Reduction, Level 2	AERO2	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	59%	67%	81%	88%	91%	92%	92%	92%	92%

7% Annual Increase - Combined

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	86%	86%	86%	85%	85%	85%	85%	85%	85%
Engine Friction Reduction - Level 1	EFR1	88%	89%	89%	89%	89%	89%	89%	89%	90%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	14%	27%	33%	39%	43%	47%	52%	57%	60%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	12%	11%	11%	11%	11%	11%	11%	11%	11%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	13%	13%	13%	12%	13%	13%	13%	13%	13%
Cylinder Deactivation on SOHC	DEACS	2%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	6%	2%	2%	2%	2%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	64%	65%	65%	64%	62%	62%	62%	62%	62%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	56%	58%	58%	59%	58%	57%	58%	58%	59%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	58%	64%	68%	70%	74%	74%	75%	76%	75%
Cylinder Deactivation on OHV	DEACO	2%	2%	1%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	10%	10%	10%	10%	9%	9%	9%	8%	8%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	8%	9%	10%	10%	10%	9%	9%	9%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	14%	13%	14%	14%	15%	13%	12%	8%	5%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	34%	31%	28%	27%	26%	23%	21%	15%	8%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	6%	7%	7%	7%	6%	5%	5%	4%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	2%	3%	3%	4%	4%	4%	3%	3%	2%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	1%	1%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	3%	7%	9%	9%	9%	8%	7%	11%	13%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	7%	9%	13%	14%	12%	13%	12%	9%	14%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	1%	3%	3%	3%	3%	2%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	1%	2%	2%	2%	3%	2%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	3%	3%	3%	3%	3%
Advanced Diesel - Small Displacement	ADSL_SD	2%	3%	4%	5%	7%	8%	8%	8%	8%
Advanced Diesel - Medium Displacement	ADSL_MD	0%	2%	3%	3%	3%	3%	3%	3%	3%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	3%	3%	2%	0%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	2%	3%	4%	5%	6%	6%	6%	6%
Improved Auto. Trans. Controls/Externals	IATC	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	15%	9%	4%	1%	0%	0%	0%	0%	0%
6-speed DCT	DCT	25%	15%	7%	2%	1%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	39%	35%	29%	24%	16%	14%	13%	12%	9%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	25%	39%	46%	51%	48%	44%	38%	37%
Shift Optimizer	SHFTOPT	21%	44%	63%	76%	82%	80%	74%	64%	58%
Electric Power Steering	EPS	72%	80%	92%	95%	95%	95%	95%	95%	96%
Improved Accessories - Level 1	IACC1	70%	78%	91%	93%	93%	94%	94%	95%	96%
Improved Accessories - Level 2	IACC2	36%	48%	63%	67%	72%	75%	77%	78%	79%
12V Micro-Hybrid (Stop-Start)	MHEV	41%	54%	67%	71%	80%	76%	69%	58%	52%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	2%	2%	1%	0%	0%	0%	0%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	1%	2%	2%	4%	5%	8%	17%	22%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	1%	1%	6%	10%	12%	12%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	75%	76%	76%	76%	76%	76%	76%	76%	75%
Mass Reduction - Level 2	MR2	30%	44%	60%	65%	68%	68%	68%	67%	67%
Mass Reduction - Level 3	MR3	22%	30%	39%	44%	47%	47%	47%	47%	47%
Mass Reduction - Level 4	MR4	6%	12%	18%	24%	28%	29%	28%	28%	28%
Mass Reduction - Level 5	MR5	1%	4%	9%	16%	21%	23%	25%	26%	27%
Low Rolling Resistance Tires - Level 1	ROLL1	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	18%	37%	51%	64%	75%	85%	89%	92%	92%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	87%	88%	88%	88%	88%	88%	89%	89%	89%
Secondary Axle Disconnect	SAX	14%	14%	16%	15%	15%	15%	15%	15%	15%
Aero Drag Reduction, Level 1	AERO1	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	60%	68%	81%	88%	91%	92%	92%	92%	92%

Max Net Benefits - Combined

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	86%	86%	86%	85%	85%	85%	85%	85%	85%
Engine Friction Reduction - Level 1	EFR1	88%	89%	89%	89%	89%	89%	89%	89%	90%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	16%	24%	33%	40%	49%	53%	63%	72%	76%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	11%	11%	11%	11%	11%	11%	11%	10%	10%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	13%	13%	12%	12%	13%	13%	12%	12%	12%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	3%	2%	2%	2%	2%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	67%	67%	67%	67%	67%	67%	68%	68%	68%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	56%	56%	56%	57%	58%	58%	59%	61%	61%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	62%	64%	64%	65%	66%	67%	67%	69%	71%
Cylinder Deactivation on OHV	DEACO	1%	1%	1%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	10%	10%	10%	10%	10%	9%	9%	9%	8%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	9%	9%	10%	10%	10%	9%	9%	9%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	17%	18%	16%	16%	14%	12%	8%	6%	5%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	33%	32%	31%	31%	30%	29%	25%	19%	14%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	8%	6%	7%	7%	6%	6%	5%	5%	3%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	2%	3%	4%	5%	6%	8%	9%	9%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	0%	1%	1%	1%	1%	1%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	2%	3%	3%	3%	3%	4%	5%	6%	9%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	9%	11%	11%	11%	10%	10%	12%	13%	16%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	1%	1%	2%	2%	3%	3%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	2%	2%	2%	5%	5%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	2%	2%	2%	3%	4%	3%	4%	4%
Advanced Diesel - Small Displacement	ADSL_SD	2%	2%	3%	3%	3%	3%	3%	3%	4%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	1%	2%	2%	2%	2%	2%	2%	2%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	3%	2%	1%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	1%	2%	3%	4%	4%	4%	4%	4%
Improved Auto. Trans. Controls/Externals	IATC	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	16%	10%	6%	2%	0%	0%	0%	0%	0%
6-speed DCT	DCT	27%	16%	11%	6%	5%	5%	4%	3%	3%
8-Speed Trans (Auto or DCT)	8SPD	35%	33%	27%	23%	17%	16%	15%	14%	11%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	24%	38%	45%	51%	52%	50%	49%	50%
Shift Optimizer	SHFTOPT	21%	44%	62%	77%	82%	84%	81%	79%	76%
Electric Power Steering	EPS	81%	84%	89%	90%	90%	90%	91%	93%	94%
Improved Accessories - Level 1	IACC1	73%	76%	78%	78%	79%	80%	80%	84%	85%
Improved Accessories - Level 2	IACC2	37%	43%	45%	50%	53%	57%	62%	63%	64%
12V Micro-Hybrid (Stop-Start)	MHEV	48%	51%	53%	53%	54%	55%	51%	48%	44%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	2%	2%	2%	2%	2%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	0%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	1%	1%	1%	2%	2%	5%	8%	10%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	0%	1%	1%	2%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	75%	76%	76%	76%	76%	76%	76%	76%	75%
Mass Reduction - Level 2	MR2	30%	44%	60%	65%	68%	68%	68%	67%	67%
Mass Reduction - Level 3	MR3	22%	30%	39%	43%	47%	47%	47%	47%	47%
Mass Reduction - Level 4	MR4	6%	10%	14%	20%	23%	24%	24%	26%	25%
Mass Reduction - Level 5	MR5	1%	4%	8%	12%	15%	16%	18%	19%	20%
Low Rolling Resistance Tires - Level 1	ROLL1	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	18%	36%	50%	64%	76%	86%	89%	92%	92%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	87%	87%	87%	88%	88%	88%	88%	88%	89%
Secondary Axle Disconnect	SAX	16%	16%	16%	15%	15%	15%	15%	15%	15%
Aero Drag Reduction, Level 1	AERO1	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	56%	64%	75%	81%	84%	87%	87%	87%	87%

Total Cost = Total Benefits - Combined

Technology	Abbr.	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Low Friction Lubricants - Level 1	LUB1	86%	86%	86%	85%	85%	85%	85%	85%	85%
Engine Friction Reduction - Level 1	EFR1	88%	89%	89%	89%	89%	89%	89%	89%	90%
Low Friction Lubricants and Engine Friction Reduction - Level 2	LUB2_EFR2	16%	24%	32%	40%	51%	55%	65%	70%	73%
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	CCPS	11%	11%	11%	11%	9%	9%	9%	8%	8%
Discrete Variable Valve Lift (DVVL) on SOHC	DVVLS	13%	13%	13%	13%	11%	10%	10%	10%	10%
Cylinder Deactivation on SOHC	DEACS	1%	1%	1%	1%	1%	0%	0%	0%	0%
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	ICP	3%	2%	2%	2%	2%	2%	2%	2%	2%
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	DCP	67%	66%	65%	65%	65%	64%	64%	64%	63%
Discrete Variable Valve Lift (DVVL) on DOHC	DVVLD	59%	57%	57%	58%	61%	60%	60%	60%	60%
Continuously Variable Valve Lift (CVVL)	CVVL	3%	3%	3%	3%	3%	3%	3%	3%	3%
Cylinder Deactivation on DOHC	DEACD	1%	1%	1%	0%	0%	0%	0%	0%	0%
Stoichiometric Gasoline Direct Injection (GDI)	SGDI	63%	67%	68%	71%	75%	75%	75%	74%	74%
Cylinder Deactivation on OHV	DEACO	1%	1%	1%	0%	0%	0%	0%	0%	0%
Variable Valve Actuation - CCP and DVVL on OHV	VVA	10%	10%	10%	10%	10%	9%	9%	9%	8%
Stoichiometric Gasoline Direct Injection (GDI) on OHV	SGDIO	9%	9%	10%	10%	10%	9%	9%	9%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) – Small Disp.	TRBDS1_SD	17%	19%	18%	19%	17%	15%	12%	5%	1%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Disp.	TRBDS1_MD	33%	32%	30%	29%	28%	26%	21%	14%	9%
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Disp.	TRBDS1_LD	8%	6%	7%	7%	7%	6%	5%	5%	3%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Disp.	TRBDS2_SD	1%	1%	2%	2%	2%	2%	2%	1%	1%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Disp.	TRBDS2_MD	0%	1%	1%	0%	1%	0%	0%	0%	0%
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displ.	TRBDS2_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 1 (24 bar BMEP) - Small Displacement	CEGR1_SD	3%	4%	7%	8%	10%	10%	12%	11%	13%
CEGR - Level 1 (24 bar BMEP) - Medium Displacement	CEGR1_MD	9%	11%	12%	13%	11%	13%	14%	14%	16%
CEGR - Level 1 (24 bar BMEP) - Large Displacement	CEGR1_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
CEGR - Level 2 (27 bar BMEP) - Small Displacement	CEGR2_SD	0%	0%	0%	0%	2%	4%	4%	8%	9%
CEGR - Level 2 (27 bar BMEP) - Medium Displacement	CEGR2_MD	0%	0%	0%	0%	2%	2%	2%	4%	5%
CEGR - Level 2 (27 bar BMEP) - Large Displacement	CEGR2_LD	0%	1%	1%	2%	3%	3%	4%	5%	4%
Advanced Diesel - Small Displacement	ADSL_SD	2%	3%	4%	4%	7%	8%	8%	9%	9%
Advanced Diesel - Medium Displacement	ADSL_MD	1%	1%	2%	2%	2%	2%	3%	3%	3%
Advanced Diesel - Large Displacement	ADSL_LD	0%	0%	0%	0%	0%	0%	0%	0%	0%
6-Speed Manual/Improved Internals	6MAN	4%	3%	2%	1%	1%	0%	0%	0%	0%
High Efficiency Gearbox (Manual)	HETRANSM	1%	2%	3%	4%	5%	6%	6%	6%	6%
Improved Auto. Trans. Controls/Externals	IATC	8%	3%	3%	0%	0%	0%	0%	0%	0%
6-Speed Trans with Improved Internals (Auto)	NAUTO	16%	10%	6%	2%	0%	0%	0%	0%	0%
6-speed DCT	DCT	27%	16%	9%	4%	1%	1%	0%	0%	0%
8-Speed Trans (Auto or DCT)	8SPD	35%	33%	27%	22%	15%	14%	13%	12%	9%
High Efficiency Gearbox (Auto or DCT)	HETRANS	10%	23%	38%	48%	55%	55%	53%	47%	47%
Shift Optimizer	SHFTOPT	21%	43%	62%	75%	85%	86%	82%	74%	69%
Electric Power Steering	EPS	85%	86%	90%	92%	93%	94%	95%	95%	96%
Improved Accessories - Level 1	IACC1	84%	86%	87%	88%	93%	94%	94%	95%	96%
Improved Accessories - Level 2	IACC2	44%	49%	53%	57%	63%	68%	74%	78%	78%
12V Micro-Hybrid (Stop-Start)	MHEV	54%	55%	59%	61%	69%	71%	69%	68%	63%
Integrated Starter Generator	ISG	0%	0%	0%	0%	0%	0%	0%	0%	0%
Strong Hybrid - Level 1	SHEV1	3%	3%	2%	2%	2%	2%	2%	2%	2%
Conversion from SHEV1 to SHEV2	SHEV1_2	0%	0%	1%	1%	1%	1%	1%	1%	1%
Strong Hybrid - Level 2	SHEV2	0%	1%	1%	2%	2%	2%	4%	12%	15%
Plug-in Hybrid - 30 mi range	PHEV1	0%	0%	0%	0%	0%	2%	4%	5%	6%
Plug-in Hybrid	PHEV2	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 75 mile range	EV1	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Early Adopter) - 100 mile range	EV2	0%	0%	0%	0%	0%	0%	0%	0%	0%

Electric Vehicle (Early Adopter) - 150 mile range	EV3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Electric Vehicle (Broad Market) - 150 mile range	EV4	0%	0%	0%	0%	0%	0%	0%	0%	0%
Fuel Cell Vehicle	FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%
Mass Reduction - Level 1	MR1	75%	76%	76%	76%	76%	76%	76%	76%	75%
Mass Reduction - Level 2	MR2	30%	44%	60%	65%	68%	68%	68%	67%	67%
Mass Reduction - Level 3	MR3	22%	30%	39%	44%	47%	47%	47%	47%	47%
Mass Reduction - Level 4	MR4	6%	11%	16%	22%	25%	25%	26%	26%	26%
Mass Reduction - Level 5	MR5	1%	4%	8%	13%	16%	18%	19%	22%	24%
Low Rolling Resistance Tires - Level 1	ROLL1	96%	98%	99%	100%	100%	100%	100%	100%	100%
Low Rolling Resistance Tires - Level 2	ROLL2	18%	37%	51%	65%	75%	86%	89%	92%	92%
Low Rolling Resistance Tires - Level 3	ROLL3	0%	0%	0%	0%	0%	0%	0%	0%	0%
Low Drag Brakes	LDB	87%	88%	88%	88%	88%	88%	89%	89%	89%
Secondary Axle Disconnect	SAX	16%	16%	16%	15%	15%	15%	15%	15%	15%
Aero Drag Reduction, Level 1	AERO1	95%	98%	100%	100%	100%	100%	100%	100%	100%
Aero Drag Reduction, Level 2	AERO2	60%	68%	81%	88%	91%	92%	92%	92%	92%

VI. MANUFACTURER CAFE CAPABILITIES

Table VI-1 shows the agencies' forecast of where the manufacturers' passenger car mpg would be, based on the MY 2008 vehicles extended into the future with no fuel economy improvements based on application of additional technology. These mpg estimates change for some of the model years, but usually to a minimal extent, and only based on changes in sales forecasts between passenger cars and light trucks.

Table VI-2 shows the **ADJUSTED BASELINE** for passenger cars. Note that when we do cost and benefit analyses, we use the **ADJUSTED BASELINE** throughout the analysis. The adjusted baseline takes each manufacturer's MY 2008 fleet and adds fuel economy-improving technologies to make it meet the MY 2016 fuel economy standard. The adjusted baseline assumes for the analysis that each manufacturer below the MY 2016 standard applicable to that manufacturer in MY 2008 (except Aston Martin, BMW, Daimler, Geely (Volvo), Lotus, Porsche, Spyker, Tata (Jaguar Land Rover), and Volkswagen) would apply technology to achieve the MY 2016 standard. We adjust the baseline because we believe that doing so is appropriate since the costs and benefits of achieving MY 2016 mpg levels have already been analyzed and estimated in the previous analysis used to establish CAFE standards for MYs 2012-2016. The costs of these technologies are therefore not considered part of this rule, and we estimate the costs and benefits of going from the adjusted baseline to the level of the alternatives.[247]

The estimated required standard levels are shown in Table VI-3 for passenger cars for the preferred alternative. The estimated average required mpg levels for cars and trucks under the proposed standards include the expected performance of the manufacturer's fleet based on calculations using the 2-cycle test and also the use of A/C efficiency improvements, but do not reflect a number of proposed flexibilities and credits that manufacturers could use for compliance that NHTSA cannot consider in establishing standards based on EPCA/EISA constraints. The flexibilities and credits that NHTSA cannot consider include the ability of manufacturers to pay civil penalties rather than achieving required CAFE levels, the ability to use statutory FFV credits, the ability to count electric vehicles for compliance, the operation of plug-in hybrid electric vehicles on electricity for compliance prior to MY 2020, and the ability to transfer and carry-forward credits. Table VI-4 provides the estimated achieved mpg levels for passenger cars for each of the alternatives. The estimated average achieved mpg levels do reflect the accounting for the flexibilities and credits mentioned above, and are based on the projections of what each manufacturer's fleet will comprise in each year of the program. Tables VI-5 through VI-8 provide the same tables for light trucks as Tables VI-1 through VI-4 show for passenger cars.

Note that not all manufacturers are assumed to attempt to "meet" the alternatives for purposes of this analysis. EPCA/EISA allows manufacturers to pay civil penalties for non-compliance;

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[247] If the manufacturer's MY 2008 fleet extended mpg level is above the level of the alternative, their mpg is assumed to remain at that level. Some manufacturers' levels go slightly above the required mpg level for them since some technologies are applied to all models of a particular manufacturer so that the exact level for each manufacturer may be slightly higher than the level of the standard and costs and benefits are estimated to that level.

essentially, to pay civil penalties *instead of* complying with the CAFE standards. Some manufacturers have historically chosen to do this instead of applying technology to improve their fuel economy, whether because civil penalties are cheaper for them than improving fuel economy, or because they would rather invest their money in other vehicle attributes that they believe their customers value more highly than fuel economy, or for some other reason. Other manufacturers may have found it more cost-effective to pay civil penalties than to apply technology, but may have chosen to apply technology anyway for other reasons – the Detroit 3 manufacturers, for example, have historically avoided paying civil penalties. We assume that Aston Martin, BMW, Daimler, Geely, Lotus, Porsche, Spyker, Tata, and Volkswagen would not meet these levels because these manufacturers have shown, in the past, willingness to pay penalties rather than spend more money to apply technologies to improve the fuel economy of their products. Because NHTSA is attempting to analyze the impacts of the CAFE standards, and because the EPCA/EISA provision allowing payment of civil penalties continues indefinitely into the future, we are assuming for purposes of this analysis that these manufacturers will continue to pay civil penalties when the cost of doing so becomes cheaper than applying additional fuel economy-improving technology.

The agency has performed an analysis of how manufacturers could respond to changes in the alternative CAFE levels. The analysis uses a technology application algorithm to systematically apply consistent cost and performance assumptions to the entire industry, as well as consistent assumptions regarding economic decision-making by manufacturers. The resulting computer model (the CAFE Compliance and Effects Model, often referred to as the "CAFE Model" or the "Volpe model"), developed by technical staff of the DOT Volpe National Transportation Systems Center in consultation with NHTSA staff, is used to help estimate the overall economic impact of the alternative CAFE standards. The CAFE model analysis shows the economic impact of the standards in terms of increases in new vehicle prices on a manufacturer-wide, industry-wide, and average per-vehicle basis. Based on these estimates and corresponding estimates of net economic and other benefits, the agency is able to consider alternatives that are economically practicable and technologically feasible.

We note that, as explained above in Chapter V, the CAFE model has been updated to account for manufacturers' ability to apply "multi-year planning" in order to minimize compliance burdens over multiple model years, and to account for manufacturers' use of CAFE credits (when specified as a model input). The model has been peer reviewed. The model documentation, including a description of the input assumptions and process, as well as peer review reports, was made available in the rulemaking docket for the August 2005 NPRM, and updated documentation is also available on NHTSA's website.[248]

Our analyses of the potential effects of alternative CAFE standards were founded on two major elements: (1) projections of the technical characteristics and sales volumes of future product offerings and (2) estimates of the applicability and incremental cost and fuel savings associated with different hardware changes—technologies—that might be utilized in response to alternative CAFE standards.

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[248] *See* Docket Nos. NHTSA-2005-22223-0003, NHTSA-2005-22223-0004 and NHTSA-2005-22223-0005, as well as NHTSA's website at http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/CAFE+Compliance+and+Effects+Modeling+System:+The+Volpe+Model.

Table VI-1

MY 2008 Fleet Extended

Estimated mpg

Passenger Cars

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	18.8	18.8	18.8	18.8	18.8
BMW	27.2	27.2	27.2	27.2	27.2
Daimler	26.0	26.1	25.9	25.5	25.5
Fiat	27.2	27.6	27.7	27.7	27.7
Ford	28.4	28.5	28.4	28.2	28.2
Geely	26.1	26.0	26.0	25.9	25.9
General Motors	28.5	28.6	28.5	28.4	28.4
Honda	33.8	34.0	34.0	33.8	33.8
Hyundai	32.2	31.1	30.9	31.7	31.7
Kia	31.8	32.0	32.3	32.7	32.7
Lotus	29.7	29.7	29.7	29.7	29.7
Mazda	30.5	30.9	30.9	30.8	30.8
Mitsubishi	29.5	29.4	29.1	28.8	28.8
Nissan	32.0	32.1	32.0	32.0	32.0
Porsche	26.2	26.2	26.2	26.2	26.2
Spyker	26.6	26.6	26.6	26.6	26.6
Subaru	29.6	29.6	29.6	29.6	29.6
Suzuki	31.2	30.8	30.8	30.8	30.8
Tata	24.6	24.6	24.6	24.6	24.6
Tesla	244.0	244.0	244.0	244.0	244.0
Toyota	35.3	35.5	35.3	35.2	35.2
Volkswagen	29.0	29.0	28.9	28.9	28.9
Total/ Average	30.6	30.6	30.6	30.6	30.7

Table VI-1 (continued)

MY 2008 Fleet Extended

Estimated mpg

Passenger Cars

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	18.8	18.8	18.8	18.8
BMW	27.2	27.2	27.2	27.2
Daimler	25.1	25.0	24.9	25.0
Fiat	28.3	28.3	28.4	28.3
Ford	28.0	28.0	28.0	28.0
Geely	26.0	26.0	26.0	26.1
General Motors	28.8	28.8	28.8	28.8
Honda	34.2	34.3	34.4	34.4
Hyundai	31.4	31.4	31.4	31.5
Kia	31.8	31.9	31.9	32.0
Lotus	29.7	29.7	29.7	29.7
Mazda	30.5	30.4	30.5	30.4
Mitsubishi	29.2	29.2	29.3	29.3
Nissan	31.6	31.6	31.6	31.6
Porsche	26.2	26.2	26.2	26.2
Spyker	26.6	26.6	26.6	26.6
Subaru	29.5	29.5	29.5	29.5
Suzuki	30.7	30.8	30.8	30.8
Tata	24.6	24.6	24.6	24.6
Tesla	244.0	244.0	244.0	244.0
Toyota	35.2	35.2	35.3	35.3
Volkswagen	28.9	28.9	28.9	28.9
Total/ Average	30.7	30.7	30.7	30.7

Table VI-2

Adjusted Baseline

Estimated mpg

Passenger Cars

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	19.8	19.8	19.9	19.9	20.7
BMW	29.8	29.8	30.3	31.1	31.7
Daimler	29.0	29.2	31.4	32.2	32.9
Fiat	31.1	34.5	35.8	36.1	36.2
Ford	31.4	34.6	34.7	35.7	37.1
Geely	28.9	31.0	32.8	32.9	34.1
General Motors	30.8	32.9	34.1	35.3	36.1
Honda	34.0	35.1	35.4	35.6	36.6
Hyundai	33.1	32.3	34.8	36.8	38.2
Kia	32.4	33.7	34.2	36.8	38.0
Lotus	31.0	31.1	31.2	31.7	31.7
Mazda	32.5	33.8	35.6	35.9	38.3
Mitsubishi	33.0	33.0	37.4	38.1	38.1
Nissan	32.7	33.6	35.7	36.6	36.8
Porsche	28.9	29.4	29.7	29.9	30.0
Spyker	30.4	31.4	33.6	33.8	34.7
Subaru	32.2	32.4	37.0	39.4	39.4
Suzuki	32.7	37.6	38.7	39.1	39.7
Tata	28.3	29.9	30.3	30.6	31.6
Tesla	255.3	260.5	269.2	279.4	281.2
Toyota	37.0	37.4	37.5	37.8	37.9
Volkswagen	30.6	33.0	33.4	33.9	35.0
Total/ Average	37.4	37.8	38.1	38.4	38.5

Table VI-2 (continued)

Adjusted Baseline

Estimated mpg

Passenger Cars

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	21.5	21.5	21.5	21.5
BMW	31.7	34.7	35.9	35.9
Daimler	33.0	33.2	34.1	35.0
Fiat	37.3	37.3	37.3	37.5
Ford	37.1	37.1	37.3	37.6
Geely	34.3	36.5	37.3	37.4
General Motors	37.3	37.4	37.5	37.5
Honda	38.2	39.1	39.5	39.5
Hyundai	37.8	37.8	38.3	38.9
Kia	37.3	38.2	38.2	38.8
Lotus	34.4	34.4	35.5	35.5
Mazda	37.9	38.5	38.8	39.0
Mitsubishi	39.0	39.0	39.1	39.3
Nissan	37.7	38.2	38.4	38.4
Porsche	33.1	34.4	34.4	34.4
Spyker	34.7	35.6	36.9	36.9
Subaru	39.4	39.4	39.4	40.1
Suzuki	39.7	39.7	41.4	41.7
Tata	32.5	34.3	34.3	35.3
Tesla	281.2	281.2	281.2	281.2
Toyota	38.8	38.9	39.0	39.3
Volkswagen	36.1	36.8	37.9	39.3
Total/ Average	38.6	38.6	38.7	38.7

Table VI-3

Estimated Required Fuel Economy Levels for Preferred Alternative

Estimated mpg

Passenger Cars

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	40.5	41.9	43.5	45.2	47.2
BMW	39.4	40.9	42.4	44.1	46.0
Daimler	37.8	39.1	40.5	42.2	44.0
Fiat	39.2	40.7	42.2	43.7	45.7
Ford	39.1	40.6	42.1	43.7	45.6
Geely	38.8	40.3	41.7	43.4	45.3
General Motors	39.3	40.7	42.3	43.9	45.8
Honda	40.5	42.0	43.6	45.3	47.3
Hyundai	40.3	41.8	43.4	45.1	47.1
Kia	40.0	41.5	43.1	44.8	46.7
Lotus	43.6	45.2	46.9	48.7	50.8
Mazda	40.5	41.9	43.5	45.2	47.1
Mitsubishi	41.1	42.6	44.2	45.9	47.9
Nissan	39.7	41.2	42.7	44.4	46.3
Porsche	43.6	45.2	46.9	48.7	50.8
Spyker	40.6	42.1	43.6	45.3	47.3
Subaru	41.7	43.2	44.8	46.6	48.6
Suzuki	43.3	44.9	46.5	48.4	50.5
Tata	36.8	38.1	39.6	41.1	42.9
Tesla	43.6	45.2	46.9	48.7	50.8
Toyota	40.7	42.2	43.8	45.5	47.5
Volkswagen	41.2	42.7	44.2	46.0	48.0
Total/ Average	40.0	41.4	43.0	44.7	46.6

Table VI-3 (continued)

Estimated Required Fuel Economy Levels for Preferred Alternative

Estimated mpg

Passenger Cars

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	49.4	51.7	54.1	56.6
BMW	48.1	50.4	52.7	55.2
Daimler	46.1	48.2	50.4	52.8
Fiat	48.0	50.2	52.7	55.1
Ford	47.7	49.9	52.3	54.7
Geely	47.4	49.6	51.9	54.4
General Motors	48.0	50.2	52.6	55.1
Honda	49.5	51.7	54.2	56.7
Hyundai	49.3	51.5	54.0	56.5
Kia	48.9	51.2	53.6	56.1
Lotus	53.2	55.7	58.3	61.1
Mazda	49.2	51.5	54.0	56.6
Mitsubishi	50.1	52.5	54.9	57.5
Nissan	48.4	50.7	53.1	55.5
Porsche	53.2	55.7	58.3	61.1
Spyker	49.5	51.8	54.2	56.8
Subaru	50.9	53.3	55.8	58.4
Suzuki	52.8	55.3	57.9	60.6
Tata	44.9	47.0	49.2	51.5
Tesla	53.2	55.7	58.3	61.1
Toyota	49.7	52.0	54.4	57.0
Volkswagen	50.2	52.6	55.0	57.6
Total/ Average	49.4	51.7	54.1	56.6

Table VI-4

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Preferred Alternative

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	38.6	40.3	40.8	45.3	46.9
Ford	38.2	40.4	43.1	45.0	46.1
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	38.4	40.6	42.0	45.6	47.8
Honda	40.1	42.7	44.9	45.3	48.9
Hyundai	40.6	41.4	45.5	46.2	48.0
Kia	39.4	41.0	42.9	47.8	50.3
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	40.1	43.1	44.4	47.2	47.2
Mitsubishi	39.8	41.6	41.8	47.2	49.8
Nissan	39.6	41.4	44.8	46.0	46.2
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.2	41.8	43.0	45.5	45.5
Suzuki	41.2	41.2	52.0	52.9	53.0
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	40.7	42.1	44.6	46.7	48.3
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	38.8	40.6	42.7	44.6	46.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Preferred Alternative (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	47.9	52.3	52.5	52.5
Ford	46.5	51.0	51.8	51.8
Geely	39.0	39.6	41.1	41.3
General Motors	47.9	49.5	50.4	55.1
Honda	50.1	53.8	54.6	56.7
Hyundai	51.7	52.4	55.9	56.0
Kia	51.3	53.2	53.3	53.4
Lotus	35.6	37.1	37.1	37.1
Mazda	50.9	51.8	53.2	58.4
Mitsubishi	50.0	50.2	50.1	71.6
Nissan	49.1	49.7	53.6	54.1
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.6	45.6	45.6	57.8
Suzuki	53.5	53.5	53.5	58.7
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	49.7	49.7	54.4	57.5
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	47.2	48.8	50.5	52.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

2% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	38.0	38.6	38.9	41.6	42.5
Ford	37.2	38.1	40.0	41.2	41.8
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	38.1	39.6	40.0	41.7	42.7
Honda	39.1	42.0	43.2	43.5	45.3
Hyundai	39.5	40.0	41.9	42.6	43.3
Kia	38.5	39.9	41.0	42.3	43.2
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	38.1	40.1	41.2	43.1	43.2
Mitsubishi	39.8	41.5	41.7	43.1	45.2
Nissan	38.5	39.9	41.8	42.5	42.9
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.2	40.6	41.7	44.6	44.6
Suzuki	40.7	40.7	48.9	49.7	50.0
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	40.1	40.6	42.0	43.3	44.4
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	38.1	39.4	40.6	41.8	42.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

2% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	43.1	44.6	44.9	44.8
Ford	43.2	43.9	44.5	44.8
Geely	39.0	39.6	41.1	41.3
General Motors	42.8	43.6	44.2	44.9
Honda	45.8	45.8	45.8	45.9
Hyundai	44.6	45.2	46.6	46.9
Kia	43.6	44.8	44.9	46.4
Lotus	35.6	37.1	37.1	37.1
Mazda	44.6	45.1	45.8	46.9
Mitsubishi	45.3	45.3	45.3	47.7
Nissan	44.2	44.2	45.1	45.2
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	44.8	44.8	44.9	48.5
Suzuki	50.5	50.5	50.6	50.6
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	44.8	44.8	46.5	46.6
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	43.3	43.8	44.5	45.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

3% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	38.4	40.3	40.5	44.9	45.5
Ford	37.7	39.4	42.1	44.2	44.9
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	38.5	40.4	41.2	43.6	45.7
Honda	39.6	43.2	45.0	45.3	47.2
Hyundai	40.3	41.0	44.7	45.3	46.5
Kia	39.0	40.4	42.0	44.2	45.8
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	39.4	41.8	43.1	45.5	45.6
Mitsubishi	39.6	41.4	41.5	44.7	47.8
Nissan	39.2	41.0	44.3	45.1	45.7
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.1	41.7	42.5	46.7	46.7
Suzuki	41.4	41.4	49.3	49.9	50.0
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	40.6	41.8	43.5	45.6	47.2
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	38.5	40.3	42.0	43.7	44.9

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

3% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	46.4	48.2	48.5	48.5
Ford	45.8	47.0	47.0	49.4
Geely	39.0	39.6	41.1	41.3
General Motors	45.9	47.0	48.6	50.3
Honda	48.3	50.2	50.6	51.8
Hyundai	48.5	49.2	50.1	50.3
Kia	46.8	47.5	47.8	51.1
Lotus	35.6	37.1	37.1	37.1
Mazda	49.4	50.1	51.0	51.4
Mitsubishi	48.0	48.1	51.3	51.4
Nissan	47.5	47.9	50.4	50.9
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	46.7	46.7	46.9	53.6
Suzuki	50.5	50.5	50.6	54.7
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	48.3	48.3	50.8	51.9
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	45.9	46.7	47.8	49.2

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

4% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	38.9	41.3	41.6	46.2	47.9
Ford	38.5	41.0	43.8	46.3	47.2
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	39.0	41.2	42.8	46.3	48.2
Honda	40.5	44.2	45.6	46.1	49.8
Hyundai	41.4	42.0	46.0	46.8	49.0
Kia	39.4	40.8	42.8	47.9	51.1
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	41.2	44.3	45.5	48.7	48.6
Mitsubishi	39.7	42.2	42.4	44.4	53.0
Nissan	40.4	41.5	46.0	47.3	47.6
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.2	41.9	42.4	46.0	46.0
Suzuki	42.2	42.3	51.5	51.9	52.3
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	40.9	42.7	45.2	48.0	49.1
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	39.1	41.1	43.2	45.4	46.8

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

4% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	48.5	52.6	53.3	53.4
Ford	47.8	50.5	52.5	53.1
Geely	39.0	39.6	41.1	41.3
General Motors	48.3	49.4	51.5	55.4
Honda	50.8	53.6	54.5	55.4
Hyundai	52.1	52.6	56.0	56.1
Kia	52.4	53.7	53.9	53.9
Lotus	35.6	37.1	37.1	37.1
Mazda	51.0	51.5	55.2	55.3
Mitsubishi	53.0	53.0	52.9	57.2
Nissan	50.6	51.4	53.6	53.9
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	46.1	46.1	50.3	61.7
Suzuki	52.8	52.8	60.3	60.4
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	50.5	50.5	54.2	57.3
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	47.8	49.0	51.0	52.8

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

5% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	39.5	42.2	42.8	47.8	49.2
Ford	39.3	42.5	44.4	47.3	51.2
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	39.9	42.5	44.2	48.0	49.9
Honda	41.8	46.3	47.8	48.4	54.4
Hyundai	43.0	43.9	48.4	49.5	51.6
Kia	39.8	39.9	44.8	51.7	53.9
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	41.6	44.9	45.9	48.7	48.7
Mitsubishi	39.7	42.2	42.4	44.4	53.0
Nissan	41.2	42.4	48.1	49.1	49.8
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.2	41.9	43.1	45.5	45.5
Suzuki	42.7	42.7	50.6	53.2	53.8
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	41.7	43.7	46.9	50.8	53.3
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	39.8	42.1	44.4	46.9	49.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

5% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	50.0	56.0	59.0	60.0
Ford	51.5	51.8	58.6	58.6
Geely	39.0	39.6	41.1	41.3
General Motors	50.2	54.0	57.9	61.0
Honda	55.6	58.5	59.8	59.8
Hyundai	53.1	53.2	67.7	67.7
Kia	54.7	55.3	55.4	61.4
Lotus	35.6	37.1	37.1	37.1
Mazda	62.0	62.3	62.2	62.5
Mitsubishi	53.0	53.0	59.9	65.6
Nissan	52.0	55.8	59.7	61.7
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.6	45.6	45.6	66.5
Suzuki	54.3	54.3	54.3	71.8
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	54.0	54.0	59.0	62.4
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	50.1	51.7	55.2	57.5

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

6% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	40.4	43.3	43.9	49.9	51.3
Ford	39.9	43.4	45.0	47.5	48.3
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	40.4	43.2	44.9	51.2	52.8
Honda	43.0	47.6	49.7	50.4	56.0
Hyundai	44.2	45.6	50.5	52.0	53.5
Kia	41.3	41.4	46.8	54.2	55.1
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	43.0	46.0	47.1	48.2	48.2
Mitsubishi	39.7	42.2	42.4	44.4	53.0
Nissan	42.2	43.5	49.2	50.6	51.3
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.2	41.8	43.1	45.7	45.6
Suzuki	44.6	44.6	49.7	50.1	51.1
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	42.3	45.3	49.0	53.8	56.7
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	40.5	43.0	45.4	48.4	50.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

6% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	56.3	61.3	61.7	65.4
Ford	48.5	51.5	56.9	60.8
Geely	39.0	39.6	41.1	41.3
General Motors	53.2	57.3	62.1	62.2
Honda	56.8	62.2	64.1	69.3
Hyundai	54.6	56.1	64.4	64.4
Kia	55.6	57.0	57.3	59.5
Lotus	35.6	37.1	37.1	37.1
Mazda	69.1	71.2	71.1	71.6
Mitsubishi	53.0	53.0	59.9	65.6
Nissan	52.2	52.9	75.8	75.5
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.6	45.6	45.6	66.6
Suzuki	51.6	51.6	64.3	75.4
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	57.2	57.2	63.5	69.7
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	51.2	53.2	57.9	61.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

7% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	41.4	44.6	45.7	52.4	52.6
Ford	40.0	43.6	45.2	47.7	48.2
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	40.6	43.4	45.1	51.1	52.7
Honda	43.8	49.5	52.1	52.6	56.1
Hyundai	45.3	47.0	51.4	53.1	53.8
Kia	41.3	42.5	47.8	54.1	55.3
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	43.4	46.1	47.2	48.5	48.6
Mitsubishi	39.7	42.2	42.4	44.4	53.0
Nissan	42.6	44.0	49.9	51.0	52.9
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.2	41.8	43.1	45.7	45.6
Suzuki	44.7	44.7	50.6	53.2	53.8
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	43.3	46.3	50.4	56.5	58.9
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	40.9	43.6	46.1	49.2	50.6

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

7% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	56.6	62.3	63.4	63.5
Ford	48.8	50.8	56.8	56.8
Geely	39.0	39.6	41.1	41.3
General Motors	52.8	58.5	60.8	63.8
Honda	56.7	65.0	70.4	77.5
Hyundai	54.6	55.8	73.7	73.9
Kia	60.7	68.2	69.0	76.7
Lotus	35.6	37.1	37.1	37.1
Mazda	61.5	63.0	62.9	72.1
Mitsubishi	53.0	53.0	59.9	65.6
Nissan	53.6	59.1	67.6	67.6
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.6	45.6	45.6	66.6
Suzuki	54.3	54.3	54.3	109.5
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	64.9	65.9	72.7	78.0
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	52.4	55.4	59.6	62.9

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Max Net Benefits, 3% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	42.5	44.0	44.4	47.2	48.2
Ford	40.1	41.3	46.9	47.8	48.5
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	42.3	43.7	44.2	45.6	48.0
Honda	44.2	46.9	48.4	48.8	49.0
Hyundai	43.7	44.0	47.6	48.6	49.0
Kia	42.1	42.2	43.3	48.7	49.9
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	42.4	45.0	45.0	51.0	50.9
Mitsubishi	40.0	42.4	42.6	43.9	52.2
Nissan	42.8	43.9	47.7	48.6	48.7
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.9	41.7	42.3	45.4	45.4
Suzuki	45.0	45.1	49.6	50.0	51.5
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	44.2	45.6	47.0	48.2	50.1
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	41.4	42.8	44.7	46.0	47.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Max Net Benefits, 3% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	48.3	49.1	49.4	49.8
Ford	48.9	49.4	49.2	49.2
Geely	39.0	39.6	41.1	41.3
General Motors	48.1	48.6	49.4	49.9
Honda	49.3	51.1	51.1	51.1
Hyundai	49.7	49.9	51.1	51.3
Kia	49.9	50.0	50.2	50.3
Lotus	35.6	37.1	37.1	37.1
Mazda	51.0	51.2	51.0	51.0
Mitsubishi	52.1	52.1	52.0	51.8
Nissan	49.5	49.8	50.8	50.9
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.4	45.3	45.5	57.8
Suzuki	51.5	51.5	58.6	58.7
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	50.2	50.3	51.2	51.6
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	47.4	48.0	48.5	49.2

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Max Net Benefits, 7% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	42.5	43.8	44.1	46.6	47.7
Ford	40.1	41.3	46.9	47.8	48.5
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	42.3	43.7	44.2	45.6	48.0
Honda	44.4	47.0	48.3	48.8	49.3
Hyundai	42.9	43.1	47.3	48.6	49.0
Kia	41.9	42.1	43.7	49.1	49.3
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	42.4	45.0	45.0	51.0	50.9
Mitsubishi	40.0	42.4	42.6	43.9	52.2
Nissan	42.8	43.9	46.9	47.7	48.1
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.9	41.7	42.3	45.4	45.4
Suzuki	45.0	45.1	49.6	50.0	51.5
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	44.2	45.6	47.2	48.6	50.1
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	41.3	42.7	44.6	46.0	47.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Max Net Benefits, 7% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	48.2	49.2	49.4	49.4
Ford	48.7	49.1	49.0	48.9
Geely	39.0	39.6	41.1	41.3
General Motors	48.1	48.6	49.4	49.9
Honda	49.6	50.6	50.8	51.5
Hyundai	49.7	49.9	50.7	50.9
Kia	49.3	49.8	49.9	50.6
Lotus	35.6	37.1	37.1	37.1
Mazda	51.0	51.2	51.0	51.0
Mitsubishi	52.1	52.1	52.0	51.8
Nissan	48.9	49.0	50.4	50.4
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.4	45.3	45.5	57.8
Suzuki	51.5	51.5	58.6	58.7
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	50.2	50.3	51.5	51.6
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	47.4	47.8	48.4	49.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Total Cost=Total Benefit, 3% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	42.5	45.4	45.9	49.8	51.0
Ford	41.1	42.3	44.1	45.4	46.1
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	42.6	44.4	45.1	46.8	49.1
Honda	45.4	48.5	50.2	50.6	54.5
Hyundai	44.6	44.9	50.4	51.0	52.7
Kia	43.3	43.4	45.1	53.4	55.2
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	43.6	46.1	46.1	47.6	47.7
Mitsubishi	40.1	42.3	42.5	43.8	52.2
Nissan	44.6	45.7	48.5	49.1	51.0
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.9	41.7	42.3	45.4	45.4
Suzuki	45.0	45.1	49.8	50.3	51.1
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	45.0	47.2	48.9	51.2	54.5
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	42.1	43.7	45.3	46.9	48.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Total Cost=Total Benefit, 3% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	53.1	54.2	57.0	57.6
Ford	46.6	52.3	56.6	57.0
Geely	39.0	39.6	41.1	41.3
General Motors	49.2	53.5	56.2	57.6
Honda	54.6	57.7	57.9	57.9
Hyundai	54.6	54.7	56.9	57.0
Kia	55.9	56.3	56.4	56.4
Lotus	35.6	37.1	37.1	37.1
Mazda	57.1	57.3	57.3	57.5
Mitsubishi	52.1	52.1	54.1	60.2
Nissan	62.4	62.8	65.1	66.3
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.4	45.3	45.5	66.6
Suzuki	51.4	51.4	64.1	64.2
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	55.0	55.0	56.9	59.8
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	50.2	52.1	53.9	55.6

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Total Cost=Total Benefit, 7% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	21.5	21.5	21.5	21.5	23.8
BMW	31.7	34.8	35.9	35.9	36.7
Daimler	33.1	33.2	34.2	35.1	35.5
Fiat	42.5	45.4	45.9	49.8	51.0
Ford	41.1	42.3	44.1	45.4	46.1
Geely	34.3	36.6	38.0	38.1	39.0
General Motors	42.6	44.4	45.1	46.8	49.1
Honda	45.4	48.5	50.2	50.6	54.5
Hyundai	44.5	44.9	50.4	51.0	52.7
Kia	43.3	43.4	45.3	52.8	54.5
Lotus	34.4	34.4	35.6	35.6	35.6
Mazda	43.6	46.1	46.1	47.6	47.7
Mitsubishi	40.1	42.3	42.5	43.8	52.2
Nissan	44.6	45.7	48.4	49.1	50.8
Porsche	33.1	34.4	34.4	34.5	35.2
Spyker	34.7	35.7	37.0	37.0	37.6
Subaru	40.9	41.7	42.3	45.4	45.4
Suzuki	45.0	45.1	49.8	50.3	51.1
Tata	32.7	34.6	34.6	35.6	36.2
Tesla	283.0	283.0	283.0	283.0	283.0
Toyota	45.0	47.2	48.9	51.2	54.5
Volkswagen	36.2	36.9	37.9	39.3	39.7
Total/ Average	42.1	43.7	45.3	46.8	48.6

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Passenger Cars

Total Cost=Total Benefit, 7% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	23.8	25.1	25.1	25.1
BMW	36.8	37.1	38.4	38.5
Daimler	36.2	37.7	37.5	40.9
Fiat	53.1	54.2	57.0	57.6
Ford	46.6	52.3	56.6	57.0
Geely	39.0	39.6	41.1	41.3
General Motors	49.2	53.5	56.2	57.6
Honda	54.6	57.7	57.9	57.9
Hyundai	54.6	54.7	56.9	57.0
Kia	55.1	55.6	55.6	55.7
Lotus	35.6	37.1	37.1	37.1
Mazda	57.1	57.3	57.3	57.5
Mitsubishi	52.1	52.1	54.1	60.2
Nissan	52.7	54.6	57.9	58.5
Porsche	35.8	35.8	36.4	36.4
Spyker	38.3	38.4	38.9	38.9
Subaru	45.4	45.3	45.5	66.6
Suzuki	51.4	51.4	64.1	64.2
Tata	37.3	38.3	38.3	38.5
Tesla	283.0	283.0	283.0	283.0
Toyota	55.0	55.0	56.9	59.8
Volkswagen	40.1	40.4	40.6	42.3
Total/ Average	49.5	51.6	53.4	55.0

Table VI-5

MY 2008 Fleet Extended

Estimated mpg

Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	22.7	22.7	22.6	22.6	22.6
Daimler	20.8	20.8	20.8	20.8	20.7
Fiat	22.2	22.3	22.3	22.3	22.4
Ford	21.2	21.3	21.4	21.4	21.4
Geely	21.1	21.1	21.1	21.1	21.1
General Motors	21.6	21.6	21.7	21.7	21.8
Honda	24.8	24.8	24.8	24.8	24.8
Hyundai	24.2	24.2	24.2	24.2	24.2
Kia	23.8	23.8	23.8	23.8	23.8
Lotus	-	-	-	-	-
Mazda	25.7	25.8	25.8	25.6	25.5
Mitsubishi	23.4	23.4	23.4	23.4	23.4
Nissan	21.9	22.0	22.1	22.1	22.1
Porsche	20.0	20.0	20.0	20.0	20.0
Spyker	19.8	19.8	19.8	19.8	19.8
Subaru	27.2	27.2	27.1	27.2	27.2
Suzuki	23.3	23.3	23.3	23.3	23.3
Tata	19.5	19.5	19.5	19.6	19.6
Tesla	-	-	-	-	-
Toyota	24.1	24.1	24.2	24.2	24.2
Volkswagen	20.1	20.1	20.1	20.1	20.1
Total/ Average	22.6	22.6	22.6	22.6	22.6

Table VI-5 (continued)

MY 2008 Fleet Extended

Estimated mpg

Light Trucks

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	22.6	22.5	22.5	22.5
Daimler	20.7	20.6	20.7	20.7
Fiat	22.4	22.4	22.4	22.4
Ford	21.3	21.4	21.5	21.5
Geely	21.1	21.1	21.1	21.1
General Motors	21.8	21.9	21.9	21.9
Honda	24.8	24.8	24.8	24.8
Hyundai	24.2	24.2	24.2	24.2
Kia	23.8	23.8	23.8	23.8
Lotus	-	-	-	-
Mazda	25.4	25.3	25.3	25.3
Mitsubishi	23.4	23.4	23.4	23.4
Nissan	22.1	22.1	22.2	22.2
Porsche	20.0	20.0	20.0	20.0
Spyker	19.8	19.8	19.8	19.8
Subaru	27.2	27.1	27.2	27.2
Suzuki	23.3	23.3	23.3	23.3
Tata	19.6	19.6	19.6	19.6
Tesla	-	-	-	-
Toyota	24.2	24.2	24.3	24.3
Volkswagen	20.1	20.1	20.1	20.1
Total/ Average	22.7	22.7	22.7	22.7

Table VI-6

Adjusted Baseline

Estimated mpg

Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	30.4	30.4	30.4	30.5	30.4
Daimler	29.2	29.2	29.2	29.1	29.0
Fiat	28.8	28.8	28.9	29.3	29.6
Ford	27.5	27.8	28.0	28.3	28.4
Geely	28.4	30.7	30.9	30.9	30.9
General Motors	27.8	27.9	28.0	28.0	28.1
Honda	30.4	30.4	30.5	30.7	30.7
Hyundai	31.0	31.0	31.0	31.0	31.0
Kia	29.5	29.5	29.5	29.5	30.5
Lotus	-	-	-	-	-
Mazda	28.9	31.9	31.9	31.7	31.5
Mitsubishi	31.8	31.8	31.8	31.8	32.2
Nissan	28.7	28.8	29.4	29.5	29.5
Porsche	26.5	27.8	29.9	29.9	29.9
Spyker	28.8	29.7	29.7	29.7	31.2
Subaru	31.4	31.8	32.5	32.5	32.8
Suzuki	32.0	32.0	32.0	32.0	32.0
Tata	26.2	26.2	26.8	26.9	29.5
Tesla	-	-	-	-	-
Toyota	28.9	29.6	29.7	29.8	29.7
Volkswagen	26.5	27.9	29.5	29.4	29.7
Total/ Average	28.6	28.9	29.1	29.2	29.3

Table VI-6 (continued)

Adjusted Baseline

Estimated mpg

Light Trucks

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	30.6	30.6	30.6	30.5
Daimler	28.9	28.9	29.0	29.0
Fiat	29.6	29.6	29.7	29.7
Ford	28.4	28.4	28.6	28.6
Geely	31.1	31.1	31.1	31.1
General Motors	28.2	28.3	28.3	28.4
Honda	30.7	30.7	30.7	30.7
Hyundai	31.0	31.0	31.0	31.0
Kia	30.5	30.5	30.5	30.5
Lotus	-	-	-	-
Mazda	31.4	31.3	31.4	31.4
Mitsubishi	32.2	32.2	32.2	32.2
Nissan	29.5	29.5	29.6	29.6
Porsche	30.3	30.3	30.3	30.3
Spyker	31.2	31.2	31.2	31.2
Subaru	32.8	32.7	32.7	32.7
Suzuki	32.0	32.0	32.0	32.0
Tata	29.5	29.5	29.7	29.7
Tesla	-	-	-	-
Toyota	29.7	29.8	29.9	29.9
Volkswagen	29.6	29.5	29.6	29.6
Total/ Average	29.3	29.4	29.4	29.4

Table VI-7

Estimated Required Fuel Economy Levels for Preferred Alternative

Estimated mpg

Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	30.6	31.4	32.1	32.9	35.1
Daimler	29.1	29.6	30.2	30.9	32.9
Fiat	29.6	30.2	30.8	31.6	33.7
Ford	28.4	29.0	29.4	29.9	31.8
Geely	31.1	32.1	32.7	33.5	35.8
General Motors	28.1	28.7	29.2	29.8	31.9
Honda	31.0	31.8	32.4	33.2	35.5
Hyundai	31.3	32.1	32.8	33.6	35.9
Kia	30.0	30.6	31.2	32.0	34.2
Lotus	-	-	-	-	-
Mazda	31.9	32.9	33.5	34.3	36.5
Mitsubishi	32.6	33.5	34.2	35.1	37.5
Nissan	29.6	30.3	30.9	31.6	33.5
Porsche	30.3	31.2	31.8	32.6	34.8
Spyker	31.2	32.1	32.8	33.6	35.9
Subaru	33.0	34.0	34.7	35.5	38.0
Suzuki	32.2	33.2	33.9	34.7	37.1
Tata	32.1	33.1	33.8	34.6	37.0
Tesla	-	-	-	-	-
Toyota	29.7	30.4	31.0	31.6	33.8
Volkswagen	29.5	30.1	30.8	31.5	33.5
Total/ Average	29.4	30.0	30.6	31.2	33.3

Table VI-7 (continued)

Estimated Required Fuel Economy Levels for Preferred Alternative

Estimated mpg

Light Trucks

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	36.7	38.4	40.2	42.1
Daimler	34.5	36.1	37.8	39.5
Fiat	35.3	37.0	38.8	40.7
Ford	33.3	35.0	36.8	38.6
Geely	37.5	39.3	41.2	43.1
General Motors	33.4	35.1	36.8	38.6
Honda	37.1	38.9	40.8	42.7
Hyundai	37.6	39.4	41.3	43.2
Kia	35.8	37.5	39.3	41.1
Lotus	-	-	-	-
Mazda	38.1	39.8	41.8	43.8
Mitsubishi	39.3	41.1	43.1	45.2
Nissan	35.1	36.9	38.7	40.6
Porsche	36.5	38.2	40.0	41.9
Spyker	37.6	39.4	41.3	43.3
Subaru	39.8	41.7	43.6	45.7
Suzuki	38.9	40.7	42.7	44.7
Tata	38.8	40.6	42.6	44.6
Tesla	-	-	-	-
Toyota	35.4	37.1	39.0	40.9
Volkswagen	35.1	36.7	38.5	40.3
Total/ Average	34.9	36.6	38.5	40.3

Table VI-8

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Preferred Alternative

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	30.6	30.8	31.1	31.7	32.4
Daimler	29.4	29.5	29.6	30.1	30.0
Fiat	29.4	29.6	30.2	33.7	34.5
Ford	27.8	29.6	30.1	30.8	34.7
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	27.7	28.8	31.3	33.1	33.6
Honda	32.3	32.5	34.3	34.9	37.3
Hyundai	32.4	32.6	36.2	36.5	36.5
Kia	30.1	30.6	31.3	31.8	38.5
Lotus	-	-	-	-	-
Mazda	30.6	36.1	36.2	36.4	36.9
Mitsubishi	33.2	34.0	34.1	35.7	42.1
Nissan	29.2	29.6	31.4	32.4	35.4
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	31.5	34.7	41.6	41.6	42.0
Suzuki	32.0	32.2	37.9	37.9	39.2
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	29.1	30.8	32.6	33.2	35.7
Volkswagen	26.5	28.1	31.7	31.7	32.2
Total/ Average	29.0	30.1	31.8	33.0	34.8

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Preferred Alternative (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	34.5	34.4	34.6	34.6
Daimler	33.6	33.6	33.7	33.9
Fiat	34.8	37.1	37.4	40.5
Ford	35.0	36.1	36.8	36.8
Geely	33.3	35.1	35.1	35.1
General Motors	33.7	34.3	35.0	37.6
Honda	40.7	41.0	41.5	42.3
Hyundai	39.4	39.4	39.4	39.4
Kia	38.5	39.4	39.3	39.7
Lotus	-	-	-	-
Mazda	36.8	40.9	43.7	43.8
Mitsubishi	42.1	42.1	42.1	42.1
Nissan	37.2	37.3	38.7	38.7
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	42.0	42.0	42.0	42.0
Suzuki	40.4	40.4	40.5	40.6
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	35.9	36.6	39.7	40.6
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	35.5	36.3	37.4	38.6

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

2% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.0	31.1	31.5	32.3	33.0
Daimler	29.4	29.5	29.6	30.1	30.0
Fiat	29.7	30.0	30.2	32.9	33.8
Ford	27.9	29.6	30.1	30.4	32.2
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	28.0	29.0	31.2	32.2	32.5
Honda	31.7	31.9	33.6	34.2	34.6
Hyundai	32.0	32.1	34.7	34.8	34.8
Kia	32.9	33.7	33.8	33.9	36.1
Lotus	-	-	-	-	-
Mazda	31.9	36.5	36.6	36.5	36.5
Mitsubishi	33.4	34.2	34.2	36.3	40.0
Nissan	29.7	30.0	31.7	32.5	34.6
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	31.6	34.7	38.2	38.2	38.2
Suzuki	32.0	32.2	36.8	36.8	37.9
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	30.1	31.6	32.5	32.7	34.0
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	29.4	30.3	31.7	32.4	33.4

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

2% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	34.5	34.4	34.6	34.6
Daimler	33.5	33.5	33.6	33.9
Fiat	34.1	35.0	35.4	35.4
Ford	32.2	33.4	33.8	34.2
Geely	33.3	35.1	35.1	35.1
General Motors	32.6	33.1	33.1	33.1
Honda	35.8	35.8	35.8	36.0
Hyundai	37.0	37.0	38.3	38.6
Kia	36.1	36.8	36.8	37.0
Lotus	-	-	-	-
Mazda	36.4	38.0	39.0	39.0
Mitsubishi	40.0	40.0	40.0	40.0
Nissan	34.6	34.7	35.4	36.3
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	38.2	38.2	40.6	40.6
Suzuki	39.0	39.0	39.2	39.2
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	34.1	34.5	35.7	36.3
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	33.7	34.2	34.7	35.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

3% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.1	31.3	31.6	32.4	33.1
Daimler	29.5	29.7	29.7	30.3	30.1
Fiat	30.1	30.4	30.7	34.8	36.2
Ford	28.1	30.7	31.2	31.8	34.5
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	28.2	29.2	31.6	33.4	33.9
Honda	33.8	34.0	36.4	37.1	38.2
Hyundai	34.1	34.3	37.7	37.9	37.9
Kia	31.7	32.3	34.1	34.7	39.0
Lotus	-	-	-	-	-
Mazda	31.9	36.6	36.7	36.9	38.5
Mitsubishi	33.5	34.9	35.0	36.3	43.0
Nissan	30.3	31.1	33.2	34.3	35.6
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	32.3	36.5	42.1	42.1	42.1
Suzuki	32.4	32.6	39.9	39.9	41.2
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	30.1	32.3	33.8	34.4	36.5
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	29.7	31.1	32.7	33.9	35.3

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

3% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	34.5	34.4	34.6	34.6
Daimler	33.6	33.6	33.7	33.9
Fiat	36.5	37.8	38.2	38.2
Ford	34.7	36.0	36.5	36.5
Geely	33.3	35.1	35.1	35.1
General Motors	34.5	35.1	35.5	37.7
Honda	40.1	40.1	40.2	40.8
Hyundai	39.9	39.9	42.0	42.4
Kia	39.0	39.3	39.3	39.4
Lotus	-	-	-	-
Mazda	38.4	40.5	42.7	42.8
Mitsubishi	43.0	43.0	43.0	43.0
Nissan	37.1	37.4	38.2	39.7
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	42.1	42.1	45.0	45.0
Suzuki	42.3	42.3	42.4	42.4
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	37.0	37.3	39.4	39.9
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	36.1	36.6	37.5	38.4

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

4% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	30.7	30.9	31.4	37.2	38.9
Ford	28.0	31.2	31.8	32.7	37.5
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	28.5	29.8	33.1	35.8	36.3
Honda	34.5	34.7	36.8	37.6	39.2
Hyundai	35.1	35.3	39.2	39.6	39.6
Kia	33.4	34.1	35.2	35.9	40.3
Lotus	-	-	-	-	-
Mazda	32.1	37.5	37.6	37.7	40.0
Mitsubishi	34.6	36.0	36.1	36.1	44.4
Nissan	30.5	31.0	33.9	35.3	38.0
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	33.1	37.4	45.1	45.2	45.2
Suzuki	33.1	33.3	41.5	41.5	42.2
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	31.2	33.9	35.7	36.3	38.0
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	30.2	31.8	33.9	35.4	37.2

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

4% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	39.0	40.9	41.4	42.2
Ford	37.9	39.5	39.9	39.9
Geely	33.3	35.1	35.1	35.1
General Motors	36.6	37.8	38.0	41.5
Honda	43.0	43.9	44.5	44.7
Hyundai	42.2	42.2	43.7	43.7
Kia	40.3	41.2	42.4	42.5
Lotus	-	-	-	-
Mazda	39.9	43.5	47.1	47.2
Mitsubishi	44.4	44.4	44.4	44.4
Nissan	40.0	40.0	40.5	42.3
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	45.2	45.2	45.2	45.2
Suzuki	42.5	42.5	42.5	45.8
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	39.0	40.5	43.3	44.1
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	38.2	39.3	40.2	41.6

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

5% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	31.4	31.6	32.4	38.4	39.7
Ford	28.4	32.3	32.9	33.9	39.8
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	28.8	30.2	33.7	36.7	37.3
Honda	35.1	35.4	36.7	37.8	41.1
Hyundai	35.9	36.2	40.7	41.3	41.3
Kia	34.0	34.3	36.0	37.5	44.7
Lotus	-	-	-	-	-
Mazda	32.4	40.6	40.7	41.3	43.0
Mitsubishi	35.4	36.9	37.0	37.0	44.9
Nissan	32.1	32.6	35.5	37.1	40.0
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	33.5	37.9	46.5	46.5	46.5
Suzuki	33.1	33.3	41.5	41.5	42.1
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	31.3	34.4	36.8	38.4	40.2
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	30.7	32.4	34.7	36.6	38.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

5% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	40.8	43.7	44.3	47.4
Ford	40.1	42.5	42.9	42.9
Geely	33.3	35.1	35.1	35.1
General Motors	37.3	38.2	39.9	44.4
Honda	46.4	46.9	47.1	47.4
Hyundai	42.8	42.8	52.4	52.4
Kia	44.7	45.0	45.0	45.2
Lotus	-	-	-	-
Mazda	42.8	44.6	49.7	49.8
Mitsubishi	44.9	44.9	44.9	44.9
Nissan	41.7	41.7	42.9	43.0
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	46.5	46.5	94.5	94.4
Suzuki	42.5	42.5	42.6	45.9
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	41.4	42.9	46.6	47.0
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	39.8	40.9	42.8	44.4

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

6% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	32.2	32.4	33.2	38.5	39.7
Ford	30.3	33.8	34.7	35.2	39.1
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	29.1	30.4	34.4	38.3	38.9
Honda	37.0	37.3	39.1	40.8	42.5
Hyundai	36.2	36.5	40.3	41.2	41.2
Kia	34.6	34.9	37.8	39.5	44.7
Lotus	-	-	-	-	-
Mazda	32.8	41.5	41.6	42.3	43.2
Mitsubishi	36.1	37.5	37.6	37.6	47.5
Nissan	32.7	33.2	36.3	37.6	40.8
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	33.4	37.5	49.7	49.8	49.8
Suzuki	33.1	33.3	41.5	41.5	42.1
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	31.5	35.4	38.4	40.2	41.4
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	31.3	33.1	35.8	37.9	39.5

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

6% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	40.9	43.7	44.3	47.4
Ford	39.2	42.3	42.6	43.7
Geely	33.3	35.1	35.1	35.1
General Motors	39.2	40.2	41.9	44.4
Honda	46.1	46.5	46.6	47.9
Hyundai	43.6	43.6	60.1	60.1
Kia	44.8	55.4	55.9	55.9
Lotus	-	-	-	-
Mazda	42.9	51.6	53.8	53.7
Mitsubishi	47.5	47.6	47.6	47.6
Nissan	41.9	41.9	43.0	49.5
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	49.9	49.8	52.4	52.4
Suzuki	42.5	42.5	42.6	45.9
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	43.0	43.8	46.9	47.6
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	40.6	41.8	43.5	45.3

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

7% Annual Increase

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	32.4	32.6	33.3	39.4	40.2
Ford	30.4	34.3	35.2	35.7	39.1
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	29.4	30.6	34.6	38.4	39.0
Honda	37.9	38.3	40.1	41.5	42.9
Hyundai	36.3	36.5	40.1	41.0	41.0
Kia	34.2	34.6	38.5	39.9	46.7
Lotus	-	-	-	-	-
Mazda	33.2	41.4	41.5	42.1	42.9
Mitsubishi	36.2	37.5	37.6	38.9	47.5
Nissan	33.1	34.0	37.1	38.2	40.0
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	34.3	38.9	47.7	47.7	47.7
Suzuki	33.1	33.3	42.5	42.5	43.2
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	31.7	35.7	39.2	40.9	42.2
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	31.6	33.5	36.2	38.3	39.7

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

7% Annual Increase (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	41.4	44.2	44.9	47.3
Ford	39.4	42.2	42.6	43.8
Geely	33.3	35.1	35.1	35.1
General Motors	39.3	40.2	42.1	44.4
Honda	55.7	55.5	58.4	58.4
Hyundai	45.8	45.9	64.6	64.5
Kia	46.8	47.7	47.8	48.0
Lotus	-	-	-	-
Mazda	42.7	53.6	54.6	54.6
Mitsubishi	47.5	47.6	47.6	47.6
Nissan	41.0	41.0	43.4	43.8
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	47.8	47.8	78.6	78.6
Suzuki	43.5	43.5	43.6	45.9
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	43.4	46.0	48.8	48.9
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	41.4	42.8	44.9	46.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Max Net Benefits, 3% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	33.0	33.3	33.6	36.6	38.8
Ford	30.9	33.1	33.6	35.0	38.8
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	30.2	31.4	34.0	36.5	37.0
Honda	38.2	38.5	40.3	42.1	43.1
Hyundai	36.0	36.3	41.1	41.8	41.8
Kia	35.4	35.7	37.6	39.9	44.5
Lotus	-	-	-	-	-
Mazda	34.8	40.5	40.5	40.8	42.8
Mitsubishi	36.2	36.4	36.6	38.0	47.8
Nissan	33.9	34.2	37.0	38.6	40.4
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	37.7	40.3	45.6	45.6	45.6
Suzuki	32.9	33.1	44.4	44.4	45.1
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	34.1	36.2	38.3	38.9	42.0
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	32.5	33.7	35.6	37.2	39.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Max Net Benefits, 3% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	38.9	41.6	42.3	46.3
Ford	39.0	42.0	42.9	43.0
Geely	33.3	35.1	35.1	35.1
General Motors	37.3	38.2	39.9	44.4
Honda	44.2	45.2	46.9	46.9
Hyundai	45.1	45.1	46.7	46.8
Kia	44.5	44.6	45.0	45.2
Lotus	-	-	-	-
Mazda	42.6	46.3	47.8	47.9
Mitsubishi	47.8	47.8	47.8	47.8
Nissan	40.6	40.9	43.1	43.2
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	45.7	45.7	54.6	54.6
Suzuki	45.1	45.1	45.2	45.9
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	42.5	43.7	45.4	46.6
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	39.5	40.7	42.2	43.9

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Max Net Benefits, 7% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	32.7	33.0	33.4	36.2	38.4
Ford	30.7	32.7	33.5	33.9	37.9
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	30.2	31.4	34.0	35.9	36.6
Honda	36.5	36.7	38.5	40.1	41.5
Hyundai	35.8	36.0	41.3	42.1	42.1
Kia	34.0	34.3	37.1	38.0	40.3
Lotus	-	-	-	-	-
Mazda	34.5	39.8	39.9	40.1	42.7
Mitsubishi	36.2	36.4	36.6	38.0	44.3
Nissan	33.2	33.5	36.6	37.0	39.4
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	35.6	37.5	45.2	45.3	45.9
Suzuki	33.1	33.3	42.3	42.3	43.0
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	32.6	34.7	36.4	37.0	39.8
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	31.9	33.1	35.0	36.2	38.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Max Net Benefits, 7% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	38.5	41.0	41.3	41.3
Ford	37.9	38.4	38.7	38.7
Geely	33.3	35.1	35.1	35.1
General Motors	36.8	37.7	38.9	39.4
Honda	42.4	42.8	42.9	42.9
Hyundai	43.7	43.7	43.7	43.7
Kia	40.4	40.8	40.9	41.3
Lotus	-	-	-	-
Mazda	42.5	42.4	42.6	42.7
Mitsubishi	44.3	44.4	44.3	44.3
Nissan	40.3	40.5	40.5	40.5
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	45.9	45.8	46.7	46.7
Suzuki	43.0	43.0	43.1	43.7
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	40.2	41.3	41.7	42.0
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	38.5	39.3	39.8	40.1

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Total Cost=Total Benefit, 3% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	33.0	33.3	33.6	36.8	38.9
Ford	30.9	32.9	33.3	34.8	39.0
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	30.2	31.4	34.0	36.5	37.0
Honda	38.3	38.5	40.3	41.9	43.1
Hyundai	36.3	36.5	41.5	42.2	42.2
Kia	35.4	35.7	37.6	39.3	44.2
Lotus	-	-	-	-	-
Mazda	34.8	39.8	39.9	40.1	42.8
Mitsubishi	36.2	36.4	36.6	38.0	47.8
Nissan	34.0	34.3	37.1	38.7	40.7
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	37.7	40.3	45.6	45.6	45.6
Suzuki	32.9	33.1	44.4	44.4	45.2
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	34.0	36.2	38.4	39.0	42.0
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	32.5	33.7	35.6	37.2	39.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Total Cost=Total Benefit, 3% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	39.1	41.8	42.5	46.3
Ford	39.2	42.2	43.2	43.2
Geely	33.3	35.1	35.1	35.1
General Motors	37.3	38.2	39.9	44.4
Honda	44.3	45.4	45.8	47.1
Hyundai	45.1	45.1	60.7	60.8
Kia	44.2	44.9	45.0	45.0
Lotus	-	-	-	-
Mazda	42.6	47.0	48.6	48.6
Mitsubishi	47.8	47.8	47.8	47.8
Nissan	40.7	41.1	43.3	43.3
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	45.7	45.7	54.6	54.6
Suzuki	45.2	45.2	45.3	45.9
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	42.4	44.7	45.9	47.2
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	39.6	41.0	42.5	44.4

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Total Cost=Total Benefit, 7% Discount Rate

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	31.6	31.8	32.3	32.4	33.3
Daimler	29.7	29.9	29.9	30.3	30.2
Fiat	33.0	33.3	33.6	36.8	38.9
Ford	30.9	32.9	33.3	34.8	39.0
Geely	28.4	31.2	31.3	31.3	31.4
General Motors	30.2	31.4	34.0	36.5	37.0
Honda	38.3	38.5	40.3	41.9	43.1
Hyundai	36.3	36.6	41.6	42.3	42.3
Kia	35.4	35.7	37.6	39.3	43.8
Lotus	-	-	-	-	-
Mazda	34.8	39.8	39.9	40.1	42.8
Mitsubishi	36.2	36.4	36.6	38.0	47.8
Nissan	34.1	34.3	37.1	38.7	40.7
Porsche	26.5	28.0	30.3	30.3	30.3
Spyker	28.8	29.8	29.9	29.9	33.6
Subaru	37.7	40.3	45.6	45.6	45.6
Suzuki	32.9	33.1	44.4	44.4	45.2
Tata	26.2	26.4	27.1	27.1	29.7
Tesla	-	-	-	-	-
Toyota	34.1	36.3	38.5	39.1	41.8
Volkswagen	26.5	28.1	31.9	31.9	32.2
Total/ Average	32.6	33.7	35.6	37.2	39.0

Estimated Achievable Fuel Economy Levels, by Alternative

Estimated mpg

Light Trucks

Total Cost=Total Benefit, 7% Discount Rate (continued)

Manufacturer	MY 2022	MY 2023	MY 2024	MY 2025
Aston Martin	-	-	-	-
BMW	35.2	35.2	35.1	35.4
Daimler	33.6	33.6	33.7	33.9
Fiat	39.1	41.8	42.5	46.3
Ford	39.2	42.2	43.2	43.2
Geely	33.3	35.1	35.1	35.1
General Motors	37.3	38.2	39.9	44.4
Honda	44.3	45.4	45.8	47.1
Hyundai	45.1	45.1	60.7	60.8
Kia	43.8	44.5	45.0	45.0
Lotus	-	-	-	-
Mazda	42.6	47.0	48.6	48.6
Mitsubishi	47.8	47.8	47.8	47.8
Nissan	40.7	41.0	43.3	43.3
Porsche	30.7	33.1	33.1	33.1
Spyker	33.6	33.6	33.6	33.6
Subaru	45.7	45.7	54.6	54.6
Suzuki	45.2	45.2	45.3	45.9
Tata	29.7	29.7	30.0	30.0
Tesla	-	-	-	-
Toyota	42.2	44.7	46.0	47.3
Volkswagen	32.3	32.8	34.5	34.5
Total/ Average	39.6	41.0	42.5	44.4

VII. COST AND SALES IMPACTS

The technology application algorithm implemented with the Volpe model was used as the basis for estimating costs for the fleet. Here, costs refer to costs or fines to manufacturers relative to the adjusted baseline of MY 2016. Manufacturers' costs or fines to bring light duty fleets into compliance with MY 2016 standards from MY 2008 levels are outside the scope of these costs as they have been addressed in the final CAFE rulemaking for MYs 2012 to 2016.

Tables VII-1a to 1v show the estimated cost per vehicle and incremental total costs in millions for the various alternatives for passenger cars. Tables VII-2a to 2v show the estimated cost per vehicle and incremental total costs in millions for the various alternatives for light trucks.

The costs for several manufacturers are the fines that these manufacturers would have to pay in addition to the technology improvements on an average vehicle basis. We assume that the costs of fines will be passed on to consumers. The incremental total cost tables show the estimated total manufacturer costs and fines in millions of dollars. Later in the analysis, when we are considering total societal costs and benefits, fines are not included, since fines are transfer payments and not technology costs.

Note that the choice of the discount rate (3% or 7%) impacts only the Max Net Benefits and Total Cost = Total Benefit scenarios. Therefore, additional detail is given in Tables VII-1 and VII-2 for these scenarios to highlight the results under both discount rates.

Table VII-1a
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Preferred Alternative
Passenger Cars

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	$84	$161	$249	$343	$453
BMW	$78	$167	$246	$336	$416
Daimler	$76	$161	$232	$325	$432
Fiat	$179	$389	$467	$1,101	$1,319
Ford	$269	$511	$881	$1,150	$1,541
Geely	$79	$162	$328	$426	$591
General Motors	$117	$422	$641	$1,228	$1,570
Honda	$67	$354	$480	$502	$919
Hyundai	$314	$388	$793	$759	$1,048
Kia	$223	$265	$471	$1,037	$1,295
Lotus	$90	$178	$266	$365	$480
Mazda	$417	$787	$855	$1,303	$1,288
Mitsubishi	$360	$755	$805	$2,222	$2,372
Nissan	$274	$408	$723	$854	$873
Porsche	$84	$172	$266	$373	$500
Spyker	$84	$161	$244	$337	$442
Subaru	$355	$435	$743	$1,068	$1,166
Suzuki	$285	$276	$1,944	$2,033	$2,025
Tata	$104	$170	$249	$331	$475
Tesla	$2	$2	$2	$2	$2
Toyota	-$4	$155	$311	$461	$598
Volkswagen	$87	$165	$252	$345	$480
Total/Average	$141	$320	$529	$767	$977

Table VII-1a (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$574	$700	$832	$970
BMW	$530	$657	$922	$1,056
Daimler	$565	$814	$946	$1,684
Fiat	$1,458	$2,277	$2,268	$2,029
Ford	$1,598	$2,689	$2,867	$2,393
Geely	$699	$894	$1,218	$1,329
General Motors	$1,564	$1,822	$1,984	$2,791
Honda	$1,035	$1,425	$1,496	$1,670
Hyundai	$1,579	$1,650	$2,235	$2,121
Kia	$1,386	$1,626	$1,607	$1,530
Lotus	$612	$750	$893	$1,047
Mazda	$2,010	$2,180	$2,515	$3,189
Mitsubishi	$2,382	$2,395	$2,536	$6,828
Nissan	$1,374	$1,514	$2,123	$2,097
Porsche	$618	$755	$898	$1,052
Spyker	$568	$696	$833	$976
Subaru	$1,285	$1,404	$1,431	$3,112
Suzuki	$2,015	$2,003	$1,953	$2,632
Tata	$756	$1,028	$1,142	$1,262
Tesla	$2	$2	$2	$2
Toyota	$708	$703	$1,286	$1,546
Volkswagen	$654	$813	$987	$1,319
Total/Average	$1,122	$1,424	$1,688	$1,926

Table VII-1b
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Preferred Alternative
Passenger Cars

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	$0	$0	$0	$0	$0
BMW	$24	$54	$85	$120	$150
Daimler	$22	$45	$65	$94	$130
Fiat	$76	$157	$186	$465	$565
Ford	$350	$670	$1,174	$1,586	$2,160
Geely	$7	$14	$30	$40	$55
General Motors	$171	$621	$958	$1,898	$2,456
Honda	$78	$403	$549	$584	$1,101
Hyundai	$186	$225	$462	$454	$643
Kia	$72	$83	$148	$336	$429
Lotus	$0	$0	$0	$0	$0
Mazda	$106	$207	$228	$352	$354
Mitsubishi	$23	$48	$51	$145	$156
Nissan	$238	$347	$618	$754	$797
Porsche	$3	$6	$10	$13	$18
Spyker	$2	$3	$5	$7	$9
Subaru	$80	$94	$161	$239	$269
Suzuki	$26	$25	$176	$190	$194
Tata	$6	$10	$14	$19	$28
Tesla	$0	$0	$0	$0	$0
Toyota	($7)	$284	$571	$868	$1,138
Volkswagen	$48	$89	$135	$191	$281
Total/Average	$1,510	$3,384	$5,628	$8,355	$10,933

Table VII-1b (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$1	$1
BMW	$191	$237	$358	$428
Daimler	$172	$254	$315	$574
Fiat	$629	$982	$983	$901
Ford	$2,261	$3,966	$4,310	$3,686
Geely	$65	$87	$121	$134
General Motors	$2,469	$2,927	$3,248	$4,671
Honda	$1,281	$1,804	$1,956	$2,239
Hyundai	$991	$1,046	$1,470	$1,436
Kia	$470	$557	$566	$555
Lotus	$0	$0	$0	$0
Mazda	$565	$647	$756	$978
Mitsubishi	$160	$162	$179	$501
Nissan	$1,288	$1,445	$2,087	$2,128
Porsche	$23	$28	$35	$43
Spyker	$12	$16	$19	$23
Subaru	$307	$339	$355	$800
Suzuki	$197	$199	$196	$272
Tata	$45	$62	$73	$83
Tesla	$0	$0	$0	$0
Toyota	$1,405	$1,431	$2,676	$3,259
Volkswagen	$388	$485	$597	$831
Total/Average	$12,919	$16,676	$20,302	$23,542

Table VII-1c
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
2% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$51	$95	$139	$189	$238
BMW	$64	$101	$142	$182	$207
Daimler	$57	$95	$133	$176	$234
Fiat	$84	$137	$172	$415	$468
Ford	$18	$114	$311	$409	$454
Geely	$51	$96	$229	$278	$387
General Motors	$63	$229	$237	$441	$547
Honda	$7	$245	$317	$346	$538
Hyundai	$212	$266	$367	$346	$411
Kia	$115	$129	$233	$272	$371
Lotus	$51	$101	$150	$200	$255
Mazda	$40	$195	$328	$548	$548
Mitsubishi	$360	$753	$738	$823	$991
Nissan	$122	$192	$374	$421	$441
Porsche	$46	$95	$151	$208	$274
Spyker	$51	$90	$139	$183	$227
Subaru	$350	$363	$647	$895	$868
Suzuki	$183	$181	$1,075	$1,137	$1,156
Tata	$71	$109	$150	$188	$282
Tesla	$2	$2	$2	$2	$2
Toyota	-$18	$20	$98	$193	$274
Volkswagen	$48	$93	$151	$192	$265
Total/Average	$53	$143	$237	$329	$400

Table VII-1c (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$288	$337	$392	$442
BMW	$255	$305	$493	$539
Daimler	$301	$479	$534	$1,189
Fiat	$517	$681	$695	$653
Ford	$643	$723	$828	$833
Geely	$424	$548	$794	$823
General Motors	$548	$637	$703	$753
Honda	$567	$550	$541	$521
Hyundai	$537	$594	$748	$745
Kia	$390	$529	$518	$681
Lotus	$304	$359	$420	$475
Mazda	$709	$757	$868	$994
Mitsubishi	$973	$946	$942	$1,309
Nissan	$598	$600	$680	$646
Porsche	$310	$365	$425	$480
Spyker	$282	$333	$393	$448
Subaru	$877	$863	$988	$1,360
Suzuki	$1,174	$1,157	$1,153	$1,090
Tata	$498	$698	$741	$784
Tesla	$2	$2	$2	$2
Toyota	$291	$289	$455	$435
Volkswagen	$368	$444	$541	$785
Total/Average	$464	$512	$595	$652

Table VII-1d
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
2% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$0	$0	$0
BMW	$20	$33	$49	$65	$74
Daimler	$16	$26	$37	$51	$70
Fiat	$36	$56	$68	$175	$200
Ford	$24	$150	$414	$564	$636
Geely	$5	$9	$21	$26	$36
General Motors	$92	$338	$354	$681	$856
Honda	$8	$279	$363	$403	$645
Hyundai	$125	$154	$214	$207	$252
Kia	$37	$40	$73	$88	$123
Lotus	$0	$0	$0	$0	$0
Mazda	$10	$51	$88	$148	$151
Mitsubishi	$23	$48	$47	$54	$65
Nissan	$106	$163	$320	$372	$402
Porsche	$2	$3	$5	$7	$10
Spyker	$1	$2	$3	$4	$5
Subaru	$78	$79	$140	$200	$200
Suzuki	$17	$16	$97	$106	$111
Tata	$4	$6	$9	$11	$17
Tesla	$0	$0	$0	$0	$0
Toyota	($33)	$37	$181	$364	$521
Volkswagen	$27	$50	$81	$106	$155
Total/Average	$598	$1,540	$2,566	$3,632	$4,530

Table VII-1d (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$0	$0	$0	$1
BMW	$92	$110	$191	$218
Daimler	$92	$150	$177	$405
Fiat	$223	$293	$301	$290
Ford	$910	$1,067	$1,245	$1,283
Geely	$39	$53	$79	$83
General Motors	$865	$1,024	$1,151	$1,260
Honda	$702	$696	$708	$698
Hyundai	$337	$377	$492	$505
Kia	$132	$181	$182	$247
Lotus	$0	$0	$0	$0
Mazda	$199	$225	$261	$305
Mitsubishi	$65	$64	$67	$96
Nissan	$561	$573	$668	$655
Porsche	$11	$13	$17	$20
Spyker	$6	$7	$9	$10
Subaru	$209	$208	$245	$349
Suzuki	$115	$115	$116	$112
Tata	$30	$42	$47	$51
Tesla	$0	$0	$0	$0
Toyota	$577	$588	$948	$917
Volkswagen	$218	$265	$328	$495
Total/Average	$5,384	$6,052	$7,233	$8,001

Table VII-1e
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
3% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$73	$139	$216	$288	$365
BMW	$92	$145	$213	$281	$334
Daimler	$79	$139	$199	$270	$355
Fiat	$152	$400	$414	$906	$905
Ford	$103	$295	$680	$974	$1,203
Geely	$73	$140	$295	$371	$508
General Motors	$122	$358	$415	$713	$1,002
Honda	$0	$321	$428	$440	$647
Hyundai	$276	$347	$663	$627	$765
Kia	$168	$180	$338	$460	$643
Lotus	$79	$156	$227	$310	$392
Mazda	$257	$481	$564	$905	$907
Mitsubishi	$224	$526	$500	$1,203	$1,453
Nissan	$209	$338	$642	$688	$752
Porsche	$73	$150	$228	$318	$412
Spyker	$73	$139	$211	$282	$359
Subaru	$233	$316	$394	$1,328	$1,300
Suzuki	$361	$349	$1,180	$1,192	$1,180
Tata	$93	$153	$216	$281	$398
Tesla	$2	$2	$2	$2	$2
Toyota	-$10	$130	$259	$418	$566
Volkswagen	$76	$143	$228	$296	$392
Total/Average	$93	$252	$409	$584	$729

Table VII-1e (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$447	$530	$612	$700
BMW	$409	$486	$707	$792
Daimler	$444	$655	$743	$1,431
Fiat	$995	$1,232	$1,249	$1,176
Ford	$1,393	$1,593	$1,626	$2,031
Geely	$578	$729	$1,009	$1,070
General Motors	$1,016	$1,185	$1,443	$1,715
Honda	$739	$907	$925	$1,017
Hyundai	$975	$1,049	$1,167	$1,121
Kia	$718	$806	$823	$1,231
Lotus	$475	$568	$656	$755
Mazda	$1,499	$1,584	$1,673	$1,610
Mitsubishi	$1,437	$1,421	$2,139	$1,860
Nissan	$973	$1,035	$1,358	$1,351
Porsche	$480	$574	$662	$761
Spyker	$441	$525	$618	$707
Subaru	$1,271	$1,435	$1,402	$2,442
Suzuki	$1,196	$1,178	$1,226	$2,039
Tata	$641	$869	$939	$1,015
Tesla	$2	$2	$2	$2
Toyota	$637	$624	$859	$895
Volkswagen	$527	$637	$767	$1,044
Total/Average	$837	$942	$1,081	$1,267

Table VII-1f
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
3% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$0	$0	$0
BMW	$29	$47	$74	$101	$120
Daimler	$22	$38	$56	$78	$107
Fiat	$65	$162	$165	$383	$387
Ford	$135	$387	$905	$1,343	$1,686
Geely	$6	$13	$27	$35	$47
General Motors	$179	$528	$620	$1,102	$1,567
Honda	$0	$366	$490	$512	$776
Hyundai	$163	$201	$387	$375	$469
Kia	$54	$56	$106	$149	$213
Lotus	$0	$0	$0	$0	$0
Mazda	$65	$126	$151	$245	$249
Mitsubishi	$15	$33	$32	$78	$96
Nissan	$182	$287	$549	$608	$686
Porsche	$3	$5	$8	$11	$15
Spyker	$1	$3	$4	$6	$8
Subaru	$52	$69	$85	$297	$300
Suzuki	$33	$31	$107	$111	$113
Tata	$5	$9	$12	$16	$23
Tesla	$0	$0	$0	$0	$0
Toyota	($18)	$239	$476	$788	$1,078
Volkswagen	$42	$77	$122	$164	$230
Total/Average	$1,033	$2,678	$4,377	$6,401	$8,170

Table VII-1f (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$0	$1	$1	$1
BMW	$147	$175	$275	$321
Daimler	$135	$205	$247	$488
Fiat	$429	$531	$541	$522
Ford	$1,971	$2,350	$2,446	$3,127
Geely	$53	$71	$100	$108
General Motors	$1,604	$1,903	$2,361	$2,870
Honda	$914	$1,148	$1,209	$1,364
Hyundai	$612	$666	$767	$759
Kia	$243	$276	$290	$446
Lotus	$0	$0	$0	$0
Mazda	$421	$470	$503	$494
Mitsubishi	$97	$96	$151	$136
Nissan	$912	$988	$1,334	$1,371
Porsche	$18	$21	$26	$31
Spyker	$10	$12	$14	$16
Subaru	$303	$347	$348	$627
Suzuki	$117	$117	$123	$210
Tata	$38	$53	$60	$66
Tesla	$0	$0	$0	$0
Toyota	$1,265	$1,271	$1,787	$1,886
Volkswagen	$313	$380	$464	$658
Total/Average	$9,603	$11,080	$13,048	$15,503

Table VII-1g
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
4% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$95	$189	$293	$392	$502
BMW	$114	$195	$285	$386	$466
Daimler	$101	$183	$271	$369	$481
Fiat	$234	$584	$588	$1,193	$1,414
Ford	$377	$718	$1,090	$1,561	$1,904
Geely	$95	$184	$372	$476	$640
General Motors	$235	$588	$822	$1,377	$1,664
Honda	$102	$491	$572	$612	$962
Hyundai	$414	$467	$904	$877	$1,188
Kia	$227	$238	$443	$1,009	$1,373
Lotus	$106	$205	$310	$420	$541
Mazda	$675	$982	$1,005	$1,544	$1,519
Mitsubishi	$349	$759	$740	$1,122	$2,654
Nissan	$377	$440	$956	$1,037	$1,065
Porsche	$101	$200	$310	$428	$560
Spyker	$95	$189	$288	$392	$497
Subaru	$355	$485	$483	$1,115	$1,220
Suzuki	$496	$482	$2,135	$2,151	$2,141
Tata	$115	$197	$282	$375	$519
Tesla	$2	$2	$2	$2	$2
Toyota	$3	$216	$409	$599	$700
Volkswagen	$98	$192	$305	$406	$535
Total/Average	$203	$421	$644	$907	$1,103

Table VII-1g (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$618	$733	$860	$986
BMW	$574	$690	$949	$1,072
Daimler	$603	$847	$968	$1,695
Fiat	$1,490	$2,321	$2,431	$2,122
Ford	$1,940	$2,632	$3,051	$2,775
Geely	$743	$927	$1,245	$1,345
General Motors	$1,646	$1,900	$2,303	$2,859
Honda	$1,059	$1,355	$1,440	$1,473
Hyundai	$1,670	$1,700	$2,465	$2,353
Kia	$1,502	$1,637	$1,640	$1,565
Lotus	$662	$788	$926	$1,063
Mazda	$2,025	$2,153	$2,975	$2,610
Mitsubishi	$2,595	$2,556	$2,508	$2,571
Nissan	$1,576	$1,736	$2,259	$2,262
Porsche	$667	$794	$931	$1,069
Spyker	$612	$734	$860	$993
Subaru	$1,305	$1,424	$2,334	$4,299
Suzuki	$2,169	$2,103	$4,093	$3,548
Tata	$795	$1,061	$1,164	$1,279
Tesla	$2	$2	$2	$2
Toyota	$829	$817	$1,259	$1,528
Volkswagen	$703	$851	$1,014	$1,335
Total/Average	$1,236	$1,466	$1,837	$1,978

Table VII-1h
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
4% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$0	$0	$1
BMW	$36	$63	$99	$138	$167
Daimler	$29	$51	$76	$107	$145
Fiat	$100	$236	$234	$504	$605
Ford	$490	$942	$1,452	$2,152	$2,669
Geely	$8	$16	$34	$44	$59
General Motors	$344	$867	$1,228	$2,128	$2,603
Honda	$118	$559	$655	$713	$1,153
Hyundai	$245	$270	$527	$525	$729
Kia	$73	$74	$140	$327	$455
Lotus	$0	$0	$0	$0	$0
Mazda	$171	$258	$268	$417	$417
Mitsubishi	$23	$48	$47	$73	$175
Nissan	$328	$374	$817	$916	$972
Porsche	$4	$7	$11	$15	$20
Spyker	$2	$4	$6	$8	$11
Subaru	$79	$105	$105	$249	$281
Suzuki	$45	$43	$193	$201	$205
Tata	$6	$11	$16	$22	$30
Tesla	$0	$0	$0	$0	$0
Toyota	$5	$397	$751	$1,129	$1,332
Volkswagen	$54	$104	$164	$225	$313
Total/Average	$2,160	$4,429	$6,823	$9,893	$12,343

Table VII-1h (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$1	$1
BMW	$207	$249	$369	$434
Daimler	$184	$265	$322	$578
Fiat	$643	$1,001	$1,054	$942
Ford	$2,746	$3,882	$4,587	$4,274
Geely	$69	$90	$124	$136
General Motors	$2,599	$3,053	$3,770	$4,786
Honda	$1,310	$1,715	$1,884	$1,974
Hyundai	$1,048	$1,078	$1,622	$1,594
Kia	$509	$561	$577	$568
Lotus	$0	$0	$0	$0
Mazda	$569	$639	$894	$801
Mitsubishi	$175	$173	$177	$188
Nissan	$1,477	$1,657	$2,220	$2,295
Porsche	$24	$29	$37	$43
Spyker	$13	$16	$20	$23
Subaru	$311	$344	$580	$1,105
Suzuki	$212	$209	$411	$366
Tata	$47	$64	$74	$84
Tesla	$0	$0	$0	$0
Toyota	$1,646	$1,663	$2,619	$3,220
Volkswagen	$417	$508	$614	$841
Total/Average	$14,207	$17,198	$21,954	$24,254

Table VII-1i
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
5% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$117	$244	$370	$508	$651
BMW	$136	$244	$362	$496	$609
Daimler	$123	$233	$348	$473	$619
Fiat	$404	$889	$892	$1,573	$1,744
Ford	$748	$1,297	$1,463	$1,932	$2,966
Geely	$117	$234	$449	$580	$778
General Motors	$483	$941	$1,168	$1,785	$2,145
Honda	$216	$666	$756	$810	$1,882
Hyundai	$675	$752	$1,291	$1,276	$1,564
Kia	$324	$264	$935	$1,497	$1,847
Lotus	$128	$260	$398	$541	$695
Mazda	$763	$1,171	$1,154	$1,590	$1,563
Mitsubishi	$343	$759	$780	$1,257	$2,654
Nissan	$548	$611	$1,347	$1,441	$1,496
Porsche	$123	$255	$398	$549	$714
Spyker	$123	$238	$365	$502	$640
Subaru	$355	$580	$714	$1,293	$1,383
Suzuki	$694	$678	$1,822	$2,353	$2,367
Tata	$137	$241	$353	$479	$656
Tesla	$2	$2	$2	$2	$2
Toyota	$89	$355	$589	$994	$1,316
Volkswagen	$120	$242	$388	$516	$683
Total/Average	$362	$648	$889	$1,205	$1,624

Table VII-1i (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$799	$959	$1,129	$1,305
BMW	$755	$910	$1,213	$1,386
Daimler	$779	$1,062	$1,221	$1,992
Fiat	$1,804	$2,908	$3,581	$3,252
Ford	$2,965	$2,967	$4,955	$4,049
Geely	$919	$1,147	$1,504	$1,653
General Motors	$2,218	$3,071	$4,152	$4,056
Honda	$1,992	$2,321	$2,500	$2,346
Hyundai	$1,808	$1,795	$4,223	$3,486
Kia	$1,945	$2,028	$2,002	$2,907
Lotus	$860	$1,036	$1,217	$1,410
Mazda	$4,763	$4,753	$4,719	$3,892
Mitsubishi	$2,597	$2,793	$4,670	$4,189
Nissan	$1,998	$2,770	$3,718	$3,740
Porsche	$865	$1,041	$1,223	$1,415
Spyker	$799	$960	$1,135	$1,312
Subaru	$1,494	$1,681	$1,819	$5,322
Suzuki	$2,442	$2,645	$2,818	$4,812
Tata	$965	$1,265	$1,412	$1,570
Tesla	$2	$2	$2	$2
Toyota	$1,384	$1,365	$2,131	$2,358
Volkswagen	$890	$1,077	$1,289	$1,665
Total/Average	$1,805	$2,099	$2,949	$2,943

Table VII-1j
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
5% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$0	$1	$1
BMW	$42	$79	$125	$177	$219
Daimler	$35	$64	$98	$138	$186
Fiat	$172	$359	$356	$664	$746
Ford	$973	$1,701	$1,949	$2,664	$4,158
Geely	$10	$21	$41	$54	$72
General Motors	$707	$1,388	$1,744	$2,758	$3,356
Honda	$249	$758	$866	$942	$2,256
Hyundai	$400	$435	$753	$763	$959
Kia	$104	$83	$294	$485	$612
Lotus	$0	$0	$0	$0	$0
Mazda	$193	$307	$308	$429	$429
Mitsubishi	$22	$48	$50	$82	$175
Nissan	$477	$519	$1,151	$1,272	$1,365
Porsche	$4	$9	$14	$20	$26
Spyker	$2	$5	$7	$11	$14
Subaru	$79	$126	$155	$289	$319
Suzuki	$63	$61	$165	$220	$227
Tata	$8	$14	$20	$28	$39
Tesla	$0	$0	$0	$0	$0
Toyota	$164	$651	$1,081	$1,872	$2,505
Volkswagen	$66	$130	$208	$286	$400
Total/Average	$3,771	$6,759	$9,385	$13,154	$18,062

Table VII-1j (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$1	$2
BMW	$272	$328	$471	$562
Daimler	$237	$332	$406	$679
Fiat	$778	$1,254	$1,552	$1,445
Ford	$4,197	$4,375	$7,450	$6,236
Geely	$85	$111	$149	$167
General Motors	$3,501	$4,933	$6,796	$6,789
Honda	$2,466	$2,937	$3,270	$3,144
Hyundai	$1,135	$1,138	$2,777	$2,361
Kia	$660	$695	$705	$1,055
Lotus	$0	$0	$0	$0
Mazda	$1,339	$1,411	$1,418	$1,194
Mitsubishi	$175	$189	$330	$307
Nissan	$1,873	$2,643	$3,654	$3,795
Porsche	$32	$39	$48	$58
Spyker	$17	$22	$26	$30
Subaru	$356	$406	$452	$1,368
Suzuki	$238	$263	$283	$496
Tata	$57	$77	$90	$103
Tesla	$0	$0	$0	$0
Toyota	$2,748	$2,780	$4,433	$4,970
Volkswagen	$528	$642	$780	$1,049
Total/Average	$20,697	$24,576	$35,094	$35,810

Table VII-1k
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
6% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$145	$293	$453	$623	$805
BMW	$158	$294	$444	$606	$763
Daimler	$145	$282	$425	$583	$762
Fiat	$620	$1,116	$1,135	$2,041	$2,201
Ford	$997	$1,658	$1,719	$2,028	$2,389
Geely	$139	$283	$526	$696	$932
General Motors	$632	$1,107	$1,338	$2,755	$2,954
Honda	$467	$939	$1,075	$1,127	$2,159
Hyundai	$892	$1,033	$1,769	$1,810	$2,077
Kia	$750	$688	$1,602	$2,230	$2,378
Lotus	$156	$321	$486	$667	$865
Mazda	$1,128	$1,455	$1,404	$1,575	$1,539
Mitsubishi	$343	$875	$978	$1,351	$2,664
Nissan	$853	$974	$1,865	$2,020	$2,098
Porsche	$150	$315	$486	$675	$885
Spyker	$145	$288	$447	$623	$799
Subaru	$355	$634	$905	$1,380	$1,489
Suzuki	$976	$958	$1,613	$1,639	$2,141
Tata	$159	$291	$430	$584	$794
Tesla	$2	$2	$2	$2	$2
Toyota	$144	$704	$1,042	$1,545	$1,874
Volkswagen	$147	$297	$470	$637	$843
Total/Average	$530	$896	$1,176	$1,617	$1,895

Table VII-1k (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1,003	$1,206	$1,432	$1,668
BMW	$948	$1,152	$1,505	$1,732
Daimler	$961	$1,287	$1,502	$2,328
Fiat	$3,634	$4,701	$4,818	$4,268
Ford	$2,561	$3,455	$5,089	$4,882
Geely	$1,106	$1,384	$1,795	$1,994
General Motors	$3,069	$4,136	$5,393	$4,663
Honda	$2,225	$3,096	$3,333	$3,791
Hyundai	$2,336	$2,815	$3,814	$3,349
Kia	$2,454	$2,663	$2,899	$3,075
Lotus	$1,074	$1,300	$1,542	$1,795
Mazda	$7,656	$7,796	$7,752	$6,206
Mitsubishi	$2,876	$3,046	$4,978	$4,453
Nissan	$2,236	$2,554	$8,845	$6,905
Porsche	$1,080	$1,305	$1,547	$1,800
Spyker	$997	$1,207	$1,432	$1,675
Subaru	$1,742	$1,835	$2,168	$5,600
Suzuki	$2,300	$2,491	$4,502	$4,669
Tata	$1,147	$1,490	$1,687	$1,895
Tesla	$2	$2	$2	$2
Toyota	$1,910	$1,882	$2,936	$3,368
Volkswagen	$1,094	$1,330	$1,597	$2,028
Total/Average	$2,154	$2,615	$3,928	$3,762

Table VII-1l
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
6% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$0	$1	$1
BMW	$49	$95	$154	$217	$274
Daimler	$41	$78	$119	$170	$229
Fiat	$264	$451	$452	$862	$942
Ford	$1,296	$2,174	$2,290	$2,796	$3,349
Geely	$12	$25	$48	$65	$86
General Motors	$925	$1,632	$1,999	$4,257	$4,621
Honda	$540	$1,069	$1,231	$1,312	$2,589
Hyundai	$528	$597	$1,031	$1,083	$1,274
Kia	$242	$215	$504	$722	$788
Lotus	$0	$0	$0	$0	$0
Mazda	$286	$382	$375	$425	$423
Mitsubishi	$22	$56	$62	$88	$175
Nissan	$742	$827	$1,594	$1,783	$1,915
Porsche	$5	$11	$18	$24	$32
Spyker	$3	$6	$9	$13	$17
Subaru	$79	$137	$196	$308	$344
Suzuki	$89	$86	$146	$153	$205
Tata	$9	$16	$25	$34	$47
Tesla	$0	$0	$0	$0	$0
Toyota	$267	$1,292	$1,914	$2,911	$3,568
Volkswagen	$81	$160	$252	$353	$494
Total/Average	$5,481	$9,310	$12,420	$17,577	$21,373

Table VII-1l (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$2	$2
BMW	$341	$415	$584	$702
Daimler	$293	$402	$499	$793
Fiat	$1,567	$2,027	$2,088	$1,896
Ford	$3,624	$5,095	$7,652	$7,519
Geely	$102	$134	$178	$202
General Motors	$4,844	$6,645	$8,828	$7,806
Honda	$2,754	$3,918	$4,359	$5,081
Hyundai	$1,467	$1,785	$2,509	$2,268
Kia	$832	$913	$1,020	$1,115
Lotus	$0	$0	$0	$1
Mazda	$2,153	$2,315	$2,330	$1,904
Mitsubishi	$193	$206	$352	$326
Nissan	$2,096	$2,437	$8,692	$7,007
Porsche	$40	$48	$61	$73
Spyker	$22	$27	$33	$39
Subaru	$416	$443	$538	$1,439
Suzuki	$224	$247	$452	$482
Tata	$68	$90	$107	$124
Tesla	$0	$0	$0	$0
Toyota	$3,793	$3,833	$6,108	$7,101
Volkswagen	$649	$793	$967	$1,278
Total/Average	$25,479	$31,777	$47,361	$47,157

Table VII-1m
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
7% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$167	$348	$541	$750	$975
BMW	$185	$343	$532	$727	$922
Daimler	$167	$332	$502	$699	$916
Fiat	$1,221	$1,676	$1,785	$2,656	$2,668
Ford	$871	$1,812	$1,843	$2,152	$2,594
Geely	$167	$338	$609	$811	$1,091
General Motors	$672	$1,146	$1,348	$2,750	$3,063
Honda	$630	$1,278	$1,394	$1,432	$1,985
Hyundai	$1,206	$1,355	$2,097	$2,157	$2,203
Kia	$761	$726	$1,718	$2,327	$2,449
Lotus	$183	$376	$579	$805	$1,047
Mazda	$1,345	$1,616	$1,614	$1,759	$1,963
Mitsubishi	$343	$942	$1,066	$1,539	$2,907
Nissan	$938	$1,060	$1,972	$2,076	$2,433
Porsche	$178	$370	$580	$813	$1,066
Spyker	$172	$343	$535	$744	$964
Subaru	$355	$692	$993	$1,554	$1,750
Suzuki	$1,002	$984	$1,820	$2,351	$2,734
Tata	$181	$340	$513	$699	$948
Tesla	$2	$2	$2	$2	$2
Toyota	$247	$798	$1,218	$1,992	$2,320
Volkswagen	$175	$352	$558	$764	$1,013
Total/Average	$614	$1,033	$1,326	$1,805	$2,018

Table VII-1m (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1,217	$1,476	$1,762	$2,070
BMW	$1,157	$1,416	$1,829	$2,123
Daimler	$1,164	$1,540	$1,810	$2,702
Fiat	$3,953	$5,352	$5,627	$4,914
Ford	$2,806	$3,862	$5,686	$4,923
Geely	$1,315	$1,642	$2,109	$2,379
General Motors	$3,310	$5,027	$5,529	$5,425
Honda	$2,041	$3,662	$4,870	$5,279
Hyundai	$2,480	$2,927	$6,046	$5,027
Kia	$3,402	$5,576	$5,665	$5,157
Lotus	$1,311	$1,591	$1,899	$2,229
Mazda	$4,783	$5,034	$5,289	$5,788
Mitsubishi	$3,090	$3,321	$5,313	$4,860
Nissan	$2,794	$4,124	$5,850	$5,098
Porsche	$1,316	$1,597	$1,905	$2,235
Spyker	$1,211	$1,477	$1,768	$2,076
Subaru	$1,976	$2,225	$2,399	$5,903
Suzuki	$2,966	$3,221	$3,500	$8,796
Tata	$1,339	$1,732	$1,984	$2,258
Tesla	$2	$2	$2	$2
Toyota	$3,372	$3,524	$4,908	$4,746
Volkswagen	$1,314	$1,605	$1,933	$2,435
Total/Average	$2,392	$3,258	$4,349	$4,188

Table VII-1n
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
7% Annual Increase
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$1	$1	$1
BMW	$58	$111	$184	$260	$331
Daimler	$47	$92	$141	$203	$275
Fiat	$519	$678	$711	$1,122	$1,142
Ford	$1,133	$2,376	$2,455	$2,967	$3,636
Geely	$15	$30	$56	$75	$101
General Motors	$983	$1,689	$2,013	$4,248	$4,792
Honda	$727	$1,454	$1,596	$1,666	$2,380
Hyundai	$714	$784	$1,222	$1,291	$1,351
Kia	$245	$227	$541	$753	$811
Lotus	$0	$0	$0	$0	$0
Mazda	$341	$424	$431	$475	$539
Mitsubishi	$22	$60	$68	$100	$191
Nissan	$817	$900	$1,685	$1,833	$2,220
Porsche	$6	$13	$21	$29	$39
Spyker	$3	$7	$11	$16	$21
Subaru	$79	$150	$216	$347	$404
Suzuki	$91	$88	$165	$220	$262
Tata	$10	$19	$29	$41	$56
Tesla	$0	$0	$0	$0	$0
Toyota	$456	$1,463	$2,236	$3,752	$4,417
Volkswagen	$96	$190	$300	$424	$593
Total/Average	$6,365	$10,756	$14,081	$19,822	$23,563

Table VII-1n (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$2	$2	$2
BMW	$417	$510	$710	$860
Daimler	$355	$481	$601	$920
Fiat	$1,705	$2,308	$2,439	$2,182
Ford	$3,971	$5,696	$8,549	$7,582
Geely	$122	$159	$209	$241
General Motors	$5,225	$8,075	$9,050	$9,081
Honda	$2,525	$4,635	$6,369	$7,076
Hyundai	$1,558	$1,857	$3,977	$3,404
Kia	$1,154	$1,911	$1,993	$1,871
Lotus	$0	$0	$1	$1
Mazda	$1,345	$1,495	$1,590	$1,776
Mitsubishi	$208	$225	$376	$356
Nissan	$2,619	$3,936	$5,749	$5,174
Porsche	$48	$59	$75	$91
Spyker	$26	$33	$40	$48
Subaru	$472	$538	$596	$1,517
Suzuki	$290	$320	$352	$907
Tata	$79	$105	$126	$148
Tesla	$0	$0	$0	$0
Toyota	$6,698	$7,179	$10,212	$10,004
Volkswagen	$780	$958	$1,170	$1,535
Total/Average	$29,596	$40,480	$54,187	$54,775

Table VII-1o
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Max Net Benefits (3% Discount Rate)
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$288	$403	$469	$535	$563
BMW	$301	$398	$461	$523	$526
Daimler	$277	$381	$436	$501	$536
Fiat	$1,612	$1,642	$1,651	$1,699	$1,760
Ford	$851	$1,105	$2,886	$2,654	$2,674
Geely	$277	$388	$543	$608	$695
General Motors	$1,171	$1,334	$1,279	$1,401	$1,584
Honda	$413	$716	$796	$827	$817
Hyundai	$718	$731	$1,075	$1,107	$1,115
Kia	$821	$756	$797	$1,235	$1,326
Lotus	$310	$436	$497	$574	$601
Mazda	$1,053	$1,341	$1,242	$3,283	$3,232
Mitsubishi	$392	$885	$1,138	$1,295	$2,571
Nissan	$837	$871	$1,237	$1,294	$1,278
Porsche	$304	$431	$497	$582	$621
Spyker	$288	$398	$464	$530	$552
Subaru	$426	$487	$938	$1,272	$1,257
Suzuki	$1,394	$1,276	$1,609	$1,620	$1,827
Tata	$286	$384	$441	$507	$574
Tesla	$2	$2	$2	$2	$2
Toyota	$283	$458	$541	$657	$809
Volkswagen	$290	$401	$487	$549	$595
Total/Average	$644	$783	$1,094	$1,195	$1,264

Table VII-1o (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$579	$607	$645	$678
BMW	$535	$563	$746	$770
Daimler	$570	$726	$776	$1,409
Fiat	$1,739	$1,805	$1,820	$1,612
Ford	$2,696	$2,742	$2,690	$2,240
Geely	$704	$806	$1,042	$1,048
General Motors	$1,557	$1,588	$1,674	$1,662
Honda	$850	$1,036	$1,015	$973
Hyundai	$1,173	$1,174	$1,329	$1,279
Kia	$1,306	$1,294	$1,286	$1,238
Lotus	$623	$651	$695	$728
Mazda	$3,215	$3,232	$3,153	$2,767
Mitsubishi	$2,503	$2,458	$2,417	$1,866
Nissan	$1,340	$1,360	$1,398	$1,339
Porsche	$629	$656	$700	$733
Spyker	$573	$602	$651	$679
Subaru	$1,261	$1,275	$1,333	$3,120
Suzuki	$1,804	$1,809	$3,693	$3,222
Tata	$762	$940	$977	$993
Tesla	$2	$2	$2	$2
Toyota	$797	$796	$870	$872
Volkswagen	$659	$719	$800	$1,022
Total/Average	$1,272	$1,324	$1,376	$1,359

Table VII-1p
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Max Net Benefits (3% Discount Rate)
Passenger Cars

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	$0	$0	$1	$1	$1
BMW	$94	$129	$159	$187	$189
Daimler	$79	$105	$123	$146	$161
Fiat	$686	$664	$658	$717	$753
Ford	$1,106	$1,449	$3,845	$3,659	$3,749
Geely	$24	$35	$50	$57	$64
General Motors	$1,712	$1,966	$1,910	$2,164	$2,477
Honda	$477	$815	$912	$962	$980
Hyundai	$425	$423	$627	$662	$684
Kia	$264	$236	$251	$400	$439
Lotus	$0	$0	$0	$0	$0
Mazda	$267	$352	$332	$887	$888
Mitsubishi	$26	$56	$73	$84	$169
Nissan	$729	$740	$1,057	$1,143	$1,167
Porsche	$11	$15	$18	$21	$23
Spyker	$6	$8	$9	$11	$12
Subaru	$96	$105	$204	$284	$290
Suzuki	$126	$115	$146	$152	$175
Tata	$16	$22	$25	$29	$34
Tesla	$0	$0	$0	$0	$0
Toyota	$523	$840	$994	$1,238	$1,540
Volkswagen	$160	$217	$261	$305	$349
Total/Average	$6,827	$8,292	$11,653	$13,108	$14,143

Table VII-1p (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$1	$1
BMW	$193	$203	$290	$312
Daimler	$174	$227	$258	$480
Fiat	$750	$778	$789	$716
Ford	$3,815	$4,044	$4,044	$3,450
Geely	$65	$78	$103	$106
General Motors	$2,458	$2,552	$2,740	$2,782
Honda	$1,052	$1,311	$1,328	$1,304
Hyundai	$737	$745	$874	$866
Kia	$443	$444	$453	$449
Lotus	$0	$0	$0	$0
Mazda	$904	$960	$948	$849
Mitsubishi	$168	$166	$171	$137
Nissan	$1,256	$1,298	$1,374	$1,359
Porsche	$23	$24	$28	$30
Spyker	$12	$13	$15	$16
Subaru	$301	$308	$331	$802
Suzuki	$176	$180	$371	$332
Tata	$45	$57	$62	$65
Tesla	$0	$0	$0	$0
Toyota	$1,584	$1,622	$1,810	$1,839
Volkswagen	$391	$429	$484	$644
Total/Average	$14,548	$15,439	$16,473	$16,539

Table VII-1q
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Max Net Benefits (7% Discount Rate)
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$288	$403	$469	$535	$563
BMW	$301	$398	$461	$523	$526
Daimler	$277	$381	$436	$501	$536
Fiat	$1,612	$1,635	$1,646	$1,666	$1,740
Ford	$848	$1,102	$2,883	$2,651	$2,671
Geely	$277	$388	$543	$608	$695
General Motors	$1,171	$1,334	$1,279	$1,401	$1,584
Honda	$451	$759	$820	$850	$891
Hyundai	$568	$583	$1,035	$1,083	$1,097
Kia	$759	$694	$790	$1,221	$1,211
Lotus	$310	$436	$497	$574	$601
Mazda	$1,053	$1,341	$1,242	$3,283	$3,232
Mitsubishi	$392	$885	$1,129	$1,295	$2,571
Nissan	$837	$871	$1,124	$1,184	$1,182
Porsche	$304	$431	$497	$582	$621
Spyker	$288	$398	$464	$530	$552
Subaru	$448	$525	$968	$1,274	$1,252
Suzuki	$1,391	$1,276	$1,609	$1,620	$1,837
Tata	$286	$384	$441	$507	$574
Tesla	$2	$2	$2	$2	$2
Toyota	$283	$458	$551	$679	$801
Volkswagen	$290	$401	$487	$549	$595
Total/Average	$637	$777	$1,086	$1,188	$1,256

Table VII-1q (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$579	$607	$645	$678
BMW	$535	$563	$746	$770
Daimler	$570	$726	$776	$1,409
Fiat	$1,748	$1,815	$1,820	$1,565
Ford	$2,689	$2,731	$2,678	$2,232
Geely	$704	$806	$1,042	$1,048
General Motors	$1,557	$1,588	$1,674	$1,666
Honda	$923	$987	$999	$1,051
Hyundai	$1,141	$1,149	$1,272	$1,220
Kia	$1,190	$1,229	$1,212	$1,258
Lotus	$623	$651	$695	$728
Mazda	$3,215	$3,232	$3,153	$2,767
Mitsubishi	$2,503	$2,458	$2,417	$1,866
Nissan	$1,248	$1,245	$1,376	$1,322
Porsche	$629	$656	$700	$733
Spyker	$573	$602	$651	$679
Subaru	$1,232	$1,273	$1,278	$3,120
Suzuki	$1,796	$1,809	$3,693	$3,222
Tata	$762	$940	$977	$993
Tesla	$2	$2	$2	$2
Toyota	$793	$792	$905	$873
Volkswagen	$659	$719	$800	$1,022
Total/Average	$1,266	$1,304	$1,371	$1,362

Table VII-1r
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Max Net Benefits (7% Discount Rate)
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$1	$1	$1
BMW	$94	$129	$159	$187	$189
Daimler	$79	$105	$123	$146	$161
Fiat	$686	$661	$656	$703	$745
Ford	$1,103	$1,445	$3,841	$3,655	$3,744
Geely	$24	$35	$50	$57	$64
General Motors	$1,712	$1,966	$1,910	$2,164	$2,477
Honda	$521	$863	$939	$989	$1,068
Hyundai	$336	$337	$603	$648	$673
Kia	$245	$217	$249	$395	$401
Lotus	$0	$0	$0	$0	$0
Mazda	$267	$352	$332	$887	$888
Mitsubishi	$26	$56	$72	$84	$169
Nissan	$729	$740	$961	$1,045	$1,079
Porsche	$11	$15	$18	$21	$23
Spyker	$6	$8	$9	$11	$12
Subaru	$100	$114	$210	$285	$289
Suzuki	$126	$115	$146	$152	$176
Tata	$16	$22	$25	$29	$34
Tesla	$0	$0	$0	$0	$0
Toyota	$523	$840	$1,012	$1,279	$1,524
Volkswagen	$160	$217	$261	$305	$349
Total/Average	$6,763	$8,237	$11,576	$13,042	$14,065

Table VII-1r (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$1	$1
BMW	$193	$203	$290	$312
Daimler	$174	$227	$258	$480
Fiat	$754	$782	$789	$695
Ford	$3,806	$4,028	$4,027	$3,438
Geely	$65	$78	$103	$106
General Motors	$2,458	$2,552	$2,740	$2,788
Honda	$1,142	$1,249	$1,306	$1,408
Hyundai	$716	$729	$836	$826
Kia	$403	$421	$426	$456
Lotus	$0	$0	$0	$0
Mazda	$904	$960	$948	$849
Mitsubishi	$168	$166	$171	$137
Nissan	$1,170	$1,189	$1,352	$1,341
Porsche	$23	$24	$28	$30
Spyker	$12	$13	$15	$16
Subaru	$294	$308	$317	$802
Suzuki	$175	$180	$371	$332
Tata	$45	$57	$62	$65
Tesla	$0	$0	$0	$0
Toyota	$1,576	$1,614	$1,883	$1,841
Volkswagen	$391	$429	$484	$644
Total/Average	$14,471	$15,210	$16,408	$16,568

Table VII-1s
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Total Cost = Total Benefit (3% Discount Rate)
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$348	$453	$535	$618	$678
BMW	$361	$448	$527	$600	$636
Daimler	$337	$431	$496	$578	$641
Fiat	$1,657	$1,936	$1,931	$2,129	$2,176
Ford	$1,314	$1,647	$1,841	$1,922	$1,964
Geely	$337	$437	$603	$690	$805
General Motors	$1,335	$1,519	$1,519	$1,713	$2,062
Honda	$646	$962	$1,071	$1,097	$1,626
Hyundai	$874	$900	$1,548	$1,503	$1,697
Kia	$1,053	$988	$1,161	$2,120	$2,418
Lotus	$376	$491	$574	$662	$728
Mazda	$1,284	$1,553	$1,433	$1,746	$1,923
Mitsubishi	$511	$915	$1,204	$1,373	$2,562
Nissan	$1,171	$1,257	$1,564	$1,649	$1,793
Porsche	$370	$486	$574	$670	$747
Spyker	$348	$447	$530	$618	$667
Subaru	$497	$542	$1,036	$1,360	$1,390
Suzuki	$1,455	$1,276	$1,616	$1,627	$1,944
Tata	$346	$434	$507	$578	$678
Tesla	$2	$2	$2	$2	$2
Toyota	$353	$721	$839	$1,095	$1,404
Volkswagen	$356	$456	$553	$632	$711
Total/Average	$814	$1,027	$1,145	$1,292	$1,502

Table VII-1s (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$810	$920	$1,030	$1,118
BMW	$761	$871	$1,120	$1,193
Daimler	$785	$1,023	$1,133	$1,816
Fiat	$2,765	$2,950	$3,647	$3,153
Ford	$2,141	$3,822	$4,848	$4,012
Geely	$924	$1,103	$1,410	$1,466
General Motors	$2,141	$3,158	$3,589	$3,246
Honda	$1,646	$1,953	$1,949	$1,859
Hyundai	$1,948	$1,959	$2,562	$2,418
Kia	$2,496	$2,578	$2,587	$2,398
Lotus	$871	$992	$1,113	$1,201
Mazda	$4,447	$4,429	$4,381	$3,842
Mitsubishi	$2,562	$2,647	$3,333	$3,265
Nissan	$4,516	$4,480	$4,747	$4,063
Porsche	$876	$997	$1,118	$1,206
Spyker	$810	$916	$1,036	$1,119
Subaru	$1,503	$1,600	$1,675	$5,331
Suzuki	$2,017	$2,146	$4,144	$3,395
Tata	$971	$1,226	$1,324	$1,394
Tesla	$2	$2	$2	$2
Toyota	$1,427	$1,408	$1,577	$1,805
Volkswagen	$901	$1,038	$1,196	$1,467
Total/Average	$1,864	$2,340	$2,696	$2,587

Table VII-1t
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Total Cost = Total Benefit (3% Discount Rate)
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$1	$1	$1
BMW	$113	$145	$182	$215	$229
Daimler	$96	$119	$140	$168	$193
Fiat	$705	$783	$769	$899	$931
Ford	$1,708	$2,160	$2,452	$2,650	$2,753
Geely	$30	$39	$55	$64	$75
General Motors	$1,952	$2,239	$2,269	$2,646	$3,225
Honda	$746	$1,095	$1,226	$1,276	$1,950
Hyundai	$517	$521	$902	$899	$1,041
Kia	$339	$309	$365	$686	$801
Lotus	$0	$0	$0	$0	$0
Mazda	$326	$408	$383	$471	$528
Mitsubishi	$33	$58	$77	$89	$169
Nissan	$1,020	$1,068	$1,337	$1,456	$1,636
Porsche	$13	$17	$21	$24	$27
Spyker	$7	$9	$11	$13	$14
Subaru	$111	$117	$225	$304	$321
Suzuki	$132	$115	$146	$152	$186
Tata	$19	$24	$29	$34	$40
Tesla	$0	$0	$0	$0	$0
Toyota	$653	$1,322	$1,542	$2,063	$2,673
Volkswagen	$196	$246	$297	$350	$416
Total/Average	$8,718	$10,795	$12,429	$14,462	$17,208

Table VII-1t (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$1	$1
BMW	$274	$314	$435	$484
Daimler	$239	$320	$377	$619
Fiat	$1,192	$1,272	$1,581	$1,400
Ford	$3,030	$5,637	$7,290	$6,178
Geely	$86	$107	$140	$148
General Motors	$3,379	$5,073	$5,875	$5,434
Honda	$2,036	$2,472	$2,549	$2,492
Hyundai	$1,224	$1,243	$1,685	$1,638
Kia	$846	$883	$910	$870
Lotus	$0	$0	$0	$0
Mazda	$1,250	$1,315	$1,317	$1,179
Mitsubishi	$172	$179	$236	$239
Nissan	$4,233	$4,276	$4,665	$4,123
Porsche	$32	$37	$44	$49
Spyker	$18	$21	$24	$26
Subaru	$359	$387	$416	$1,370
Suzuki	$197	$213	$416	$350
Tata	$58	$74	$84	$91
Tesla	$0	$0	$0	$0
Toyota	$2,835	$2,869	$3,281	$3,805
Volkswagen	$535	$620	$724	$925
Total/Average	$21,996	$27,312	$32,051	$31,421

Table VII-1u
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Total Cost = Total Benefit (7% Discount Rate)
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$348	$453	$535	$618	$678
BMW	$361	$448	$527	$600	$636
Daimler	$337	$431	$496	$578	$641
Fiat	$1,657	$1,936	$1,931	$2,129	$2,176
Ford	$1,314	$1,647	$1,768	$1,922	$1,977
Geely	$337	$437	$603	$690	$805
General Motors	$1,335	$1,519	$1,519	$1,713	$2,062
Honda	$646	$962	$1,071	$1,097	$1,626
Hyundai	$872	$898	$1,546	$1,503	$1,697
Kia	$1,053	$988	$1,303	$2,038	$2,334
Lotus	$376	$491	$574	$662	$728
Mazda	$1,284	$1,553	$1,433	$1,746	$1,923
Mitsubishi	$511	$915	$1,204	$1,373	$2,562
Nissan	$1,171	$1,257	$1,554	$1,639	$1,731
Porsche	$370	$486	$574	$670	$747
Spyker	$348	$447	$530	$618	$667
Subaru	$503	$542	$1,036	$1,360	$1,390
Suzuki	$1,455	$1,276	$1,616	$1,627	$1,944
Tata	$346	$434	$507	$578	$678
Tesla	$2	$2	$2	$2	$2
Toyota	$353	$721	$839	$1,095	$1,404
Volkswagen	$356	$456	$553	$632	$711
Total/Average	$814	$1,027	$1,149	$1,289	$1,494

Table VII-1u (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$810	$920	$1,030	$1,118
BMW	$761	$871	$1,120	$1,193
Daimler	$785	$1,023	$1,133	$1,816
Fiat	$2,765	$2,950	$3,647	$3,153
Ford	$2,141	$3,834	$4,848	$4,012
Geely	$924	$1,103	$1,410	$1,466
General Motors	$2,141	$3,158	$3,589	$3,246
Honda	$1,646	$1,953	$1,949	$1,859
Hyundai	$1,948	$1,959	$2,562	$2,418
Kia	$2,409	$2,501	$2,548	$2,324
Lotus	$871	$992	$1,113	$1,201
Mazda	$4,447	$4,429	$4,381	$3,842
Mitsubishi	$2,562	$2,647	$3,333	$3,265
Nissan	$2,131	$2,485	$3,061	$2,877
Porsche	$876	$997	$1,118	$1,206
Spyker	$810	$916	$1,036	$1,119
Subaru	$1,503	$1,600	$1,675	$5,331
Suzuki	$2,017	$2,146	$4,144	$3,395
Tata	$971	$1,226	$1,324	$1,394
Tesla	$2	$2	$2	$2
Toyota	$1,427	$1,408	$1,577	$1,805
Volkswagen	$901	$1,038	$1,196	$1,467
Total/Average	$1,653	$2,164	$2,547	$2,480

Table VII-1v
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Total Cost = Total Benefit (7% Discount Rate)
Passenger Cars

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	$0	$0	$1	$1	$1
BMW	$113	$145	$182	$215	$229
Daimler	$96	$119	$140	$168	$193
Fiat	$705	$783	$769	$899	$931
Ford	$1,708	$2,160	$2,354	$2,650	$2,772
Geely	$30	$39	$55	$64	$75
General Motors	$1,952	$2,239	$2,269	$2,646	$3,225
Honda	$746	$1,095	$1,226	$1,276	$1,950
Hyundai	$516	$520	$901	$899	$1,041
Kia	$339	$309	$410	$660	$773
Lotus	$0	$0	$0	$0	$0
Mazda	$326	$408	$383	$471	$528
Mitsubishi	$33	$58	$77	$89	$169
Nissan	$1,020	$1,068	$1,328	$1,447	$1,580
Porsche	$13	$17	$21	$24	$27
Spyker	$7	$9	$11	$13	$14
Subaru	$113	$117	$225	$304	$321
Suzuki	$132	$115	$146	$152	$186
Tata	$19	$24	$29	$34	$40
Tesla	$0	$0	$0	$0	$0
Toyota	$653	$1,322	$1,542	$2,063	$2,673
Volkswagen	$196	$246	$297	$350	$416
Total/Average	$8,718	$10,794	$12,366	$14,427	$17,142

Table VII-1v (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	$1	$1	$1	$1
BMW	$274	$314	$435	$484
Daimler	$239	$320	$377	$619
Fiat	$1,192	$1,272	$1,581	$1,400
Ford	$3,030	$5,654	$7,290	$6,178
Geely	$86	$107	$140	$148
General Motors	$3,379	$5,073	$5,875	$5,434
Honda	$2,036	$2,472	$2,549	$2,492
Hyundai	$1,224	$1,243	$1,685	$1,638
Kia	$817	$857	$897	$843
Lotus	$0	$0	$0	$0
Mazda	$1,250	$1,315	$1,317	$1,179
Mitsubishi	$172	$179	$236	$239
Nissan	$1,998	$2,371	$3,008	$2,919
Porsche	$32	$37	$44	$49
Spyker	$18	$21	$24	$26
Subaru	$359	$387	$416	$1,370
Suzuki	$197	$213	$416	$350
Tata	$58	$74	$84	$91
Tesla	$0	$0	$0	$0
Toyota	$2,835	$2,869	$3,281	$3,805
Volkswagen	$535	$620	$724	$925
Total/Average	$19,731	$25,398	$30,380	$30,190

Table VII-2a
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Preferred Alternative
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$48	$71	$145	$300	$489
Daimler	$48	$59	$85	$187	$328
Fiat	$57	$66	$138	$691	$803
Ford	$42	$345	$356	$482	$1,212
Geely	$7	$142	$145	$199	$332
General Motors	-$13	$134	$411	$711	$708
Honda	$278	$281	$460	$486	$723
Hyundai	$214	$223	$676	$702	$678
Kia	$79	$119	$191	$266	$841
Lotus	-	-	-	-	-
Mazda	$251	$365	$322	$350	$415
Mitsubishi	$226	$263	$227	$384	$2,206
Nissan	$55	$83	$225	$393	$775
Porsche	$1	$84	$109	$153	$274
Spyker	$7	$63	$101	$144	$572
Subaru	$7	$460	$1,199	$1,164	$1,122
Suzuki	$1	$13	$664	$629	$904
Tata	$18	$74	$143	$193	$290
Tesla	-	-	-	-	-
Toyota	$22	$171	$363	$407	$693
Volkswagen	$7	$69	$350	$358	$449
Total/Average	$57	$178	$359	$524	$755

Table VII-2a (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$865	$958	$1,095	$1,150
Daimler	$1,184	$1,267	$1,321	$1,358
Fiat	$847	$1,216	$1,255	$1,930
Ford	$1,259	$1,494	$1,543	$1,457
Geely	$593	$1,007	$1,101	$1,154
General Motors	$692	$782	$924	$1,512
Honda	$1,140	$1,171	$1,234	$1,318
Hyundai	$1,058	$1,037	$1,024	$983
Kia	$826	$907	$893	$928
Lotus	-	-	-	-
Mazda	$408	$1,024	$1,469	$1,406
Mitsubishi	$2,170	$2,121	$2,089	$2,019
Nissan	$1,152	$1,128	$1,358	$1,289
Porsche	$394	$921	$1,008	$1,052
Spyker	$660	$754	$853	$928
Subaru	$1,124	$1,110	$1,094	$1,047
Suzuki	$1,140	$1,124	$1,138	$1,065
Tata	$389	$489	$593	$703
Tesla	-	-	-	-
Toyota	$682	$784	$1,168	$1,292
Volkswagen	$580	$769	$1,179	$1,203
Total/Average	$863	$976	$1,141	$1,348

Table VII-2b
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Preferred Alternative
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$7	$9	$19	$38	$63
Daimler	$4	$5	$8	$17	$33
Fiat	$23	$26	$51	$249	$280
Ford	$32	$259	$256	$345	$865
Geely	$0	$6	$6	$8	$14
General Motors	($18)	$193	$619	$1,088	$1,083
Honda	$166	$153	$242	$255	$388
Hyundai	$33	$34	$105	$108	$106
Kia	$8	$12	$19	$26	$80
Lotus	-	-	-	-	-
Mazda	$13	$21	$18	$20	$25
Mitsubishi	$9	$10	$8	$14	$78
Nissan	$24	$34	$90	$156	$316
Porsche	$0	$1	$1	$2	$3
Spyker	$0	$0	$0	$1	$2
Subaru	$1	$35	$87	$84	$82
Suzuki	$0	$0	$14	$13	$19
Tata	$1	$4	$8	$11	$17
Tesla	-	-	-	-	-
Toyota	$29	$210	$414	$470	$843
Volkswagen	$1	$10	$51	$53	$67
Total/Average	$332	$1,021	$2,019	$2,959	$4,362

Table VII-2b (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$112	$122	$161	$167
Daimler	$119	$133	$141	$137
Fiat	$308	$439	$433	$640
Ford	$899	$1,046	$1,063	$997
Geely	$25	$42	$47	$49
General Motors	$1,044	$1,170	$1,381	$2,305
Honda	$615	$628	$663	$735
Hyundai	$167	$167	$170	$165
Kia	$78	$87	$86	$91
Lotus	-	-	-	-
Mazda	$25	$63	$91	$86
Mitsubishi	$76	$75	$75	$73
Nissan	$475	$471	$573	$550
Porsche	$4	$10	$12	$12
Spyker	$2	$3	$3	$3
Subaru	$82	$81	$81	$78
Suzuki	$24	$23	$24	$23
Tata	$23	$29	$34	$40
Tesla	-	-	-	-
Toyota	$842	$960	$1,411	$1,564
Volkswagen	$85	$118	$185	$186
Total/Average	$5,003	$5,670	$6,633	$7,902

Table VII-2c
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
2% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$134	$195	$270	$424	$532
Daimler	$48	$98	$135	$277	$300
Fiat	$151	$159	$161	$556	$600
Ford	$83	$281	$301	$288	$497
Geely	$67	$197	$206	$259	$305
General Motors	$36	$159	$345	$460	$457
Honda	$169	$176	$305	$364	$398
Hyundai	$158	$168	$537	$538	$516
Kia	$461	$517	$434	$440	$616
Lotus	-	-	-	-	-
Mazda	$368	$413	$367	$364	$362
Mitsubishi	$257	$293	$256	$507	$1,086
Nissan	$136	$137	$288	$385	$615
Porsche	$56	$133	$170	$208	$246
Spyker	$67	$123	$161	$205	$545
Subaru	$27	$389	$663	$637	$604
Suzuki	$1	$13	$503	$471	$748
Tata	$78	$129	$203	$254	$257
Tesla	-	-	-	-	-
Toyota	$155	$267	$349	$356	$450
Volkswagen	$51	$124	$396	$434	$448
Total/Average	$114	$204	$319	$395	$471

Table VII-2c (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$783	$826	$903	$897
Daimler	$1,098	$1,110	$1,105	$1,113
Fiat	$632	$720	$771	$733
Ford	$488	$694	$761	$825
Geely	$510	$869	$903	$890
General Motors	$448	$488	$479	$457
Honda	$506	$499	$495	$486
Hyundai	$731	$713	$821	$837
Kia	$606	$671	$656	$663
Lotus	-	-	-	-
Mazda	$353	$533	$627	$594
Mitsubishi	$1,069	$1,049	$1,024	$985
Nissan	$615	$610	$672	$851
Porsche	$311	$783	$816	$799
Spyker	$578	$616	$655	$659
Subaru	$615	$609	$1,013	$954
Suzuki	$914	$901	$919	$860
Tata	$301	$346	$384	$428
Tesla	-	-	-	-
Toyota	$439	$455	$584	$664
Volkswagen	$503	$643	$992	$961
Total/Average	$509	$564	$626	$648

Table VII-2d
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
2% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$18	$26	$36	$54	$69
Daimler	$4	$8	$12	$26	$30
Fiat	$62	$62	$59	$201	$209
Ford	$63	$210	$216	$206	$355
Geely	$3	$8	$9	$11	$13
General Motors	$48	$229	$520	$704	$699
Honda	$101	$96	$161	$191	$213
Hyundai	$24	$25	$84	$83	$81
Kia	$45	$51	$44	$42	$59
Lotus	-	-	-	-	-
Mazda	$19	$24	$21	$21	$21
Mitsubishi	$10	$11	$9	$18	$38
Nissan	$61	$56	$115	$153	$251
Porsche	$1	$2	$2	$2	$3
Spyker	$0	$0	$1	$1	$2
Subaru	$2	$29	$48	$46	$44
Suzuki	$0	$0	$10	$10	$16
Tata	$5	$7	$12	$14	$15
Tesla	-	-	-	-	-
Toyota	$206	$326	$398	$411	$547
Volkswagen	$7	$18	$58	$64	$67
Total/Average	$679	$1,190	$1,814	$2,259	$2,730

Table VII-2d (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$101	$105	$132	$130
Daimler	$111	$117	$118	$112
Fiat	$229	$260	$266	$243
Ford	$349	$486	$524	$565
Geely	$21	$37	$38	$38
General Motors	$675	$730	$716	$697
Honda	$273	$268	$266	$271
Hyundai	$115	$115	$136	$141
Kia	$57	$64	$63	$65
Lotus	-	-	-	-
Mazda	$21	$33	$39	$36
Mitsubishi	$38	$37	$37	$36
Nissan	$253	$254	$284	$363
Porsche	$4	$9	$9	$9
Spyker	$2	$2	$2	$2
Subaru	$45	$44	$75	$71
Suzuki	$19	$19	$19	$18
Tata	$18	$20	$22	$24
Tesla	-	-	-	-
Toyota	$542	$558	$705	$804
Volkswagen	$74	$99	$156	$148
Total/Average	$2,947	$3,258	$3,609	$3,774

Table VII-2e
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
3% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$180	$257	$353	$528	$665
Daimler	$77	$148	$221	$363	$421
Fiat	$282	$284	$308	$1,038	$1,182
Ford	$94	$522	$527	$634	$1,238
Geely	$89	$236	$266	$336	$409
General Motors	$99	$218	$439	$796	$820
Honda	$487	$493	$666	$722	$826
Hyundai	$449	$454	$860	$860	$838
Kia	$191	$229	$301	$385	$891
Lotus	-	-	-	-	-
Mazda	$368	$494	$446	$481	$559
Mitsubishi	$297	$477	$430	$525	$1,690
Nissan	$222	$245	$449	$586	$832
Porsche	$73	$172	$230	$285	$351
Spyker	$84	$162	$222	$282	$649
Subaru	$182	$768	$1,272	$1,247	$1,190
Suzuki	$109	$120	$1,044	$1,002	$1,268
Tata	$100	$167	$269	$342	$367
Tesla	-	-	-	-	-
Toyota	$157	$352	$489	$532	$773
Volkswagen	$67	$157	$434	$511	$564
Total/Average	$187	$327	$477	$666	$853

Table VII-2e (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$915	$974	$1,079	$1,100
Daimler	$1,228	$1,278	$1,305	$1,309
Fiat	$1,214	$1,427	$1,522	$1,452
Ford	$1,264	$1,528	$1,562	$1,461
Geely	$642	$1,023	$1,085	$1,104
General Motors	$889	$971	$1,045	$1,531
Honda	$1,058	$1,044	$1,037	$1,066
Hyundai	$1,171	$1,154	$1,538	$1,516
Kia	$860	$900	$885	$861
Lotus	-	-	-	-
Mazda	$552	$922	$1,257	$1,210
Mitsubishi	$1,646	$1,623	$1,602	$1,510
Nissan	$1,147	$1,173	$1,292	$1,600
Porsche	$438	$937	$992	$1,003
Spyker	$710	$770	$836	$873
Subaru	$1,191	$1,178	$1,595	$1,520
Suzuki	$1,459	$1,439	$1,438	$1,336
Tata	$433	$505	$577	$648
Tesla	-	-	-	-
Toyota	$814	$836	$1,126	$1,161
Volkswagen	$624	$786	$1,162	$1,153
Total/Average	$964	$1,047	$1,176	$1,313

Table VII-2f
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
3% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$25	$34	$46	$68	$86
Daimler	$7	$12	$20	$34	$42
Fiat	$116	$110	$113	$375	$412
Ford	$72	$391	$378	$455	$884
Geely	$4	$10	$11	$14	$17
General Motors	$135	$314	$661	$1,219	$1,254
Honda	$291	$268	$351	$379	$443
Hyundai	$69	$69	$134	$133	$131
Kia	$19	$22	$30	$37	$85
Lotus	-	-	-	-	-
Mazda	$19	$28	$26	$28	$33
Mitsubishi	$11	$17	$15	$18	$60
Nissan	$99	$101	$179	$233	$340
Porsche	$1	$2	$3	$3	$4
Spyker	$0	$1	$1	$1	$2
Subaru	$14	$58	$93	$90	$87
Suzuki	$2	$3	$22	$21	$26
Tata	$6	$9	$16	$19	$21
Tesla	-	-	-	-	-
Toyota	$209	$431	$558	$614	$940
Volkswagen	$9	$23	$64	$75	$84
Total/Average	$1,106	$1,904	$2,720	$3,816	$4,951

Table VII-2f (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$118	$124	$158	$160
Daimler	$124	$135	$140	$132
Fiat	$441	$515	$525	$482
Ford	$903	$1,070	$1,076	$1,000
Geely	$27	$43	$46	$47
General Motors	$1,341	$1,453	$1,561	$2,333
Honda	$571	$561	$557	$595
Hyundai	$184	$186	$256	$255
Kia	$81	$86	$85	$84
Lotus	-	-	-	-
Mazda	$33	$57	$78	$74
Mitsubishi	$58	$58	$58	$55
Nissan	$473	$489	$546	$682
Porsche	$5	$11	$11	$11
Spyker	$2	$3	$3	$3
Subaru	$87	$86	$118	$114
Suzuki	$30	$30	$30	$29
Tata	$25	$30	$33	$37
Tesla	-	-	-	-
Toyota	$1,006	$1,025	$1,360	$1,405
Volkswagen	$92	$121	$182	$178
Total/Average	$5,600	$6,081	$6,822	$7,675

Table VII-2g
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
4% Annual Increase
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$313	$404	$554	$647	$822
Daimler	$140	$233	$323	$457	$531
Fiat	$501	$496	$539	$1,960	$2,224
Ford	$94	$694	$704	$857	$2,202
Geely	$106	$274	$332	$424	$519
General Motors	$219	$493	$1,149	$1,878	$1,903
Honda	$581	$584	$737	$826	$1,007
Hyundai	$659	$665	$1,196	$1,203	$1,168
Kia	$500	$554	$624	$705	$1,099
Lotus	-	-	-	-	-
Mazda	$416	$549	$494	$526	$815
Mitsubishi	$609	$783	$731	$722	$2,658
Nissan	$332	$350	$803	$1,100	$1,546
Porsche	$95	$210	$291	$373	$455
Spyker	$106	$200	$288	$370	$759
Subaru	$336	$921	$2,089	$2,055	$1,986
Suzuki	$424	$430	$2,604	$2,538	$2,561
Tata	$117	$211	$330	$430	$483
Tesla	-	-	-	-	-
Toyota	$356	$598	$755	$782	$1,060
Volkswagen	$84	$195	$495	$593	$668
Total/Average	$314	$525	$832	$1,181	$1,496

Table VII-2g (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,178	$1,261	$1,354	$1,449
Daimler	$1,354	$1,438	$1,486	$1,529
Fiat	$2,218	$2,628	$2,808	$2,826
Ford	$2,241	$2,801	$2,805	$2,616
Geely	$780	$1,194	$1,283	$1,341
General Motors	$1,897	$2,242	$2,240	$3,093
Honda	$1,605	$1,725	$1,802	$1,743
Hyundai	$1,990	$1,961	$2,393	$2,406
Kia	$1,073	$1,209	$1,450	$1,395
Lotus	-	-	-	-
Mazda	$808	$1,578	$2,212	$2,091
Mitsubishi	$2,596	$2,554	$2,518	$2,403
Nissan	$1,984	$1,946	$2,051	$2,538
Porsche	$575	$1,102	$1,190	$1,228
Spyker	$847	$941	$1,040	$1,110
Subaru	$1,974	$1,944	$1,914	$1,826
Suzuki	$2,536	$2,493	$2,455	$2,776
Tata	$582	$681	$786	$890
Tesla	-	-	-	-
Toyota	$1,185	$1,408	$1,859	$1,900
Volkswagen	$756	$945	$1,349	$1,373
Total/Average	$1,661	$1,917	$2,066	$2,300

Table VII-2h
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
4% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$43	$53	$73	$83	$106
Daimler	$12	$20	$28	$42	$53
Fiat	$205	$192	$197	$707	$775
Ford	$72	$520	$505	$614	$1,573
Geely	$4	$12	$14	$18	$22
General Motors	$299	$709	$1,730	$2,875	$2,911
Honda	$347	$318	$389	$434	$540
Hyundai	$101	$101	$186	$186	$183
Kia	$49	$54	$63	$68	$105
Lotus	-	-	-	-	-
Mazda	$22	$32	$28	$31	$48
Mitsubishi	$23	$28	$26	$25	$94
Nissan	$148	$144	$320	$438	$631
Porsche	$1	$3	$3	$4	$5
Spyker	$0	$1	$1	$1	$3
Subaru	$26	$69	$152	$149	$145
Suzuki	$9	$9	$54	$52	$53
Tata	$7	$12	$19	$24	$28
Tesla	-	-	-	-	-
Toyota	$474	$732	$863	$903	$1,288
Volkswagen	$11	$28	$73	$87	$99
Total/Average	$1,853	$3,038	$4,725	$6,741	$8,661

Table VII-2h (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$152	$161	$198	$211
Daimler	$137	$151	$159	$154
Fiat	$805	$949	$969	$937
Ford	$1,601	$1,961	$1,932	$1,791
Geely	$33	$50	$54	$57
General Motors	$2,860	$3,356	$3,346	$4,714
Honda	$866	$926	$968	$972
Hyundai	$313	$316	$398	$405
Kia	$102	$116	$139	$136
Lotus	-	-	-	-
Mazda	$49	$98	$137	$128
Mitsubishi	$91	$91	$91	$87
Nissan	$817	$812	$866	$1,082
Porsche	$7	$13	$14	$14
Spyker	$3	$3	$4	$4
Subaru	$144	$142	$142	$136
Suzuki	$53	$52	$52	$59
Tata	$34	$40	$46	$51
Tesla	-	-	-	-
Toyota	$1,464	$1,725	$2,246	$2,299
Volkswagen	$111	$146	$212	$212
Total/Average	$9,639	$11,106	$11,971	$13,450

Table VII-2i
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
5% Annual Increase
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$329	$448	$614	$735	$938
Daimler	$162	$272	$383	$539	$641
Fiat	$870	$836	$887	$2,407	$2,693
Ford	$269	$1,207	$1,220	$1,406	$3,399
Geely	$122	$313	$398	$518	$640
General Motors	$386	$718	$1,558	$2,408	$2,396
Honda	$656	$656	$737	$904	$1,504
Hyundai	$828	$833	$1,730	$1,781	$1,739
Kia	$703	$722	$907	$1,089	$2,133
Lotus	-	-	-	-	-
Mazda	$489	$1,586	$1,486	$1,635	$1,791
Mitsubishi	$812	$975	$923	$910	$2,783
Nissan	$845	$846	$1,363	$1,808	$2,347
Porsche	$111	$254	$351	$461	$571
Spyker	$122	$239	$354	$463	$880
Subaru	$385	$1,052	$2,608	$2,567	$2,494
Suzuki	$424	$474	$2,604	$2,538	$2,555
Tata	$139	$255	$401	$523	$609
Tesla	-	-	-	-	-
Toyota	$387	$779	$1,042	$1,315	$1,639
Volkswagen	$106	$234	$555	$676	$784
Total/Average	$467	$776	$1,168	$1,634	$2,087

Table VII-2i (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,326	$1,442	$1,574	$1,702
Daimler	$1,492	$1,603	$1,690	$1,765
Fiat	$3,104	$3,644	$3,906	$4,433
Ford	$3,399	$4,184	$4,209	$3,717
Geely	$934	$1,381	$1,508	$1,599
General Motors	$2,354	$2,725	$3,307	$4,241
Honda	$2,445	$2,480	$2,520	$2,459
Hyundai	$2,304	$2,388	$4,559	$3,632
Kia	$2,097	$2,152	$2,117	$2,158
Lotus	-	-	-	-
Mazda	$1,736	$2,273	$3,914	$3,446
Mitsubishi	$2,762	$2,792	$2,961	$2,833
Nissan	$2,878	$2,832	$3,118	$3,191
Porsche	$718	$1,284	$1,404	$1,487
Spyker	$1,001	$1,128	$1,260	$1,374
Subaru	$2,475	$2,565	$10,941	$8,281
Suzuki	$2,683	$2,773	$2,897	$3,053
Tata	$736	$874	$1,011	$1,165
Tesla	-	-	-	-
Toyota	$1,836	$2,059	$3,291	$3,247
Volkswagen	$893	$1,116	$1,558	$1,621
Total/Average	$2,311	$2,552	$3,210	$3,331

Table VII-2j
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
5% Annual Increase
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$45	$59	$81	$94	$121
Daimler	$14	$23	$34	$50	$64
Fiat	$356	$324	$325	$868	$939
Ford	$206	$904	$875	$1,008	$2,428
Geely	$5	$13	$17	$22	$27
General Motors	$526	$1,032	$2,345	$3,686	$3,665
Honda	$391	$358	$389	$474	$806
Hyundai	$127	$126	$269	$275	$272
Kia	$69	$71	$91	$105	$204
Lotus	-	-	-	-	-
Mazda	$25	$91	$85	$95	$106
Mitsubishi	$31	$35	$33	$32	$98
Nissan	$376	$349	$543	$719	$958
Porsche	$1	$3	$4	$5	$6
Spyker	$0	$1	$1	$2	$3
Subaru	$30	$79	$190	$186	$181
Suzuki	$9	$10	$54	$52	$53
Tata	$8	$14	$23	$29	$35
Tesla	-	-	-	-	-
Toyota	$515	$953	$1,190	$1,518	$1,992
Volkswagen	$14	$34	$82	$99	$117
Total/Average	$2,750	$4,481	$6,631	$9,320	$12,075

Table VII-2j (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$171	$184	$231	$248
Daimler	$151	$169	$181	$178
Fiat	$1,127	$1,316	$1,347	$1,471
Ford	$2,428	$2,929	$2,899	$2,544
Geely	$39	$58	$64	$68
General Motors	$3,549	$4,079	$4,939	$6,464
Honda	$1,319	$1,331	$1,353	$1,371
Hyundai	$363	$385	$757	$611
Kia	$199	$206	$203	$211
Lotus	-	-	-	-
Mazda	$105	$141	$243	$211
Mitsubishi	$97	$99	$107	$103
Nissan	$1,185	$1,181	$1,316	$1,361
Porsche	$8	$15	$16	$17
Spyker	$3	$4	$4	$5
Subaru	$180	$187	$811	$619
Suzuki	$56	$58	$61	$65
Tata	$43	$51	$59	$66
Tesla	-	-	-	-
Toyota	$2,268	$2,523	$3,976	$3,928
Volkswagen	$131	$172	$245	$250
Total/Average	$13,420	$15,087	$18,813	$19,791

Table VII-2k
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
6% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$351	$486	$680	$828	$1,064
Daimler	$179	$310	$449	$627	$757
Fiat	$1,175	$1,137	$1,187	$2,424	$2,722
Ford	$1,118	$2,187	$2,263	$2,204	$3,336
Geely	$144	$357	$464	$611	$767
General Motors	$499	$832	$1,727	$3,146	$3,150
Honda	$1,157	$1,158	$1,354	$1,618	$1,997
Hyundai	$1,158	$1,162	$1,772	$1,892	$1,906
Kia	$1,005	$1,025	$1,433	$1,682	$2,671
Lotus	-	-	-	-	-
Mazda	$616	$1,768	$1,662	$1,859	$1,898
Mitsubishi	$1,260	$1,383	$1,296	$1,272	$3,744
Nissan	$1,158	$1,145	$1,628	$1,835	$2,570
Porsche	$133	$293	$417	$554	$697
Spyker	$144	$283	$420	$557	$1,012
Subaru	$369	$962	$3,424	$3,361	$3,287
Suzuki	$424	$518	$2,604	$2,550	$2,632
Tata	$161	$299	$467	$622	$741
Tesla	-	-	-	-	-
Toyota	$447	$1,196	$1,677	$2,052	$2,176
Volkswagen	$122	$278	$621	$769	$899
Total/Average	$733	$1,132	$1,600	$2,187	$2,487

Table VII-2k (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,486	$1,640	$1,811	$1,994
Daimler	$1,640	$1,790	$1,915	$2,035
Fiat	$3,202	$3,887	$4,212	$4,725
Ford	$3,461	$4,749	$4,964	$4,744
Geely	$1,093	$1,579	$1,756	$1,896
General Motors	$3,143	$3,576	$4,193	$4,550
Honda	$2,850	$2,950	$3,104	$3,223
Hyundai	$2,393	$2,698	$5,824	$4,496
Kia	$2,625	$5,017	$5,062	$3,952
Lotus	-	-	-	-
Mazda	$1,832	$4,205	$4,502	$4,147
Mitsubishi	$3,729	$3,849	$3,975	$3,924
Nissan	$2,983	$3,097	$3,424	$4,839
Porsche	$878	$1,476	$1,641	$1,773
Spyker	$1,166	$1,331	$1,507	$1,671
Subaru	$3,256	$3,201	$3,730	$3,683
Suzuki	$2,850	$2,987	$3,150	$3,361
Tata	$906	$1,083	$1,270	$1,467
Tesla	-	-	-	-
Toyota	$2,617	$2,589	$3,713	$3,831
Volkswagen	$1,047	$1,303	$1,789	$1,896
Total/Average	$2,735	$3,067	$3,549	$3,670

Table VII-2l
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
6% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$48	$64	$89	$106	$137
Daimler	$16	$26	$40	$58	$75
Fiat	$481	$441	$435	$874	$949
Ford	$854	$1,638	$1,624	$1,580	$2,383
Geely	$6	$15	$20	$26	$32
General Motors	$680	$1,196	$2,598	$4,816	$4,820
Honda	$690	$631	$714	$849	$1,070
Hyundai	$177	$176	$276	$292	$298
Kia	$99	$101	$144	$162	$255
Lotus	-	-	-	-	-
Mazda	$32	$102	$96	$108	$112
Mitsubishi	$47	$50	$46	$45	$132
Nissan	$515	$472	$649	$730	$1,049
Porsche	$2	$4	$5	$6	$8
Spyker	$0	$1	$2	$2	$4
Subaru	$29	$72	$249	$244	$239
Suzuki	$9	$11	$54	$53	$55
Tata	$9	$17	$27	$35	$43
Tesla	-	-	-	-	-
Toyota	$595	$1,463	$1,915	$2,369	$2,645
Volkswagen	$16	$40	$91	$113	$134
Total/Average	$4,307	$6,520	$9,075	$12,468	$14,440

Table VII-2l (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$191	$209	$265	$290
Daimler	$166	$188	$205	$206
Fiat	$1,162	$1,404	$1,453	$1,568
Ford	$2,472	$3,325	$3,420	$3,247
Geely	$46	$66	$75	$81
General Motors	$4,738	$5,353	$6,262	$6,935
Honda	$1,537	$1,584	$1,667	$1,797
Hyundai	$377	$435	$967	$756
Kia	$249	$480	$487	$386
Lotus	-	-	-	-
Mazda	$110	$261	$279	$255
Mitsubishi	$131	$137	$143	$143
Nissan	$1,228	$1,292	$1,446	$2,063
Porsche	$10	$17	$19	$20
Spyker	$4	$5	$5	$6
Subaru	$237	$234	$277	$275
Suzuki	$59	$62	$67	$72
Tata	$53	$64	$74	$83
Tesla	-	-	-	-
Toyota	$3,232	$3,172	$4,485	$4,636
Volkswagen	$154	$201	$281	$293
Total/Average	$16,156	$18,485	$21,875	$23,110

Table VII-2m
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
7% Annual Increase
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$368	$530	$752	$927	$1,202
Daimler	$195	$349	$515	$721	$883
Fiat	$1,245	$1,206	$1,236	$2,923	$3,044
Ford	$1,195	$2,363	$2,425	$2,367	$3,186
Geely	$166	$401	$536	$716	$904
General Motors	$762	$1,003	$1,869	$3,187	$3,302
Honda	$1,628	$1,620	$1,851	$2,098	$2,134
Hyundai	$1,213	$1,214	$1,777	$1,892	$1,944
Kia	$581	$597	$1,043	$1,232	$3,491
Lotus	-	-	-	-	-
Mazda	$743	$1,657	$1,520	$1,737	$1,956
Mitsubishi	$1,283	$1,383	$1,377	$1,363	$3,793
Nissan	$1,294	$1,300	$1,769	$2,111	$2,592
Porsche	$150	$337	$489	$653	$829
Spyker	$166	$327	$491	$661	$1,150
Subaru	$417	$1,411	$2,935	$2,863	$2,792
Suzuki	$424	$567	$2,704	$2,725	$2,826
Tata	$177	$343	$544	$727	$884
Tesla	-	-	-	-	-
Toyota	$578	$1,333	$1,843	$2,217	$2,304
Volkswagen	$139	$316	$687	$863	$1,031
Total/Average	$894	$1,287	$1,739	$2,330	$2,529

Table VII-2m (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,662	$1,860	$2,080	$2,313
Daimler	$1,805	$1,993	$2,163	$2,337
Fiat	$3,683	$4,349	$4,716	$5,037
Ford	$3,531	$4,914	$5,135	$4,964
Geely	$1,275	$1,804	$2,025	$2,226
General Motors	$3,419	$3,767	$4,463	$4,813
Honda	$5,172	$5,085	$5,603	$4,483
Hyundai	$3,444	$3,608	$6,626	$5,225
Kia	$3,424	$3,553	$3,851	$3,696
Lotus	-	-	-	-
Mazda	$2,019	$4,746	$4,975	$4,876
Mitsubishi	$3,916	$4,080	$4,261	$4,271
Nissan	$3,069	$3,205	$4,123	$4,152
Porsche	$1,048	$1,691	$1,910	$2,092
Spyker	$1,342	$1,551	$1,782	$2,001
Subaru	$3,047	$2,981	$9,934	$8,028
Suzuki	$3,069	$3,255	$3,471	$3,702
Tata	$1,088	$1,314	$1,550	$1,814
Tesla	-	-	-	-
Toyota	$2,794	$3,322	$4,387	$4,310
Volkswagen	$1,212	$1,512	$2,042	$2,204
Total/Average	$3,010	$3,405	$4,047	$3,829

Table VII-2n
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
7% Annual Increase
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$51	$70	$99	$119	$155
Daimler	$17	$29	$45	$67	$88
Fiat	$510	$468	$453	$1,054	$1,061
Ford	$913	$1,769	$1,741	$1,697	$2,275
Geely	$7	$17	$23	$30	$38
General Motors	$1,039	$1,442	$2,813	$4,878	$5,051
Honda	$971	$882	$976	$1,102	$1,144
Hyundai	$185	$184	$277	$292	$304
Kia	$57	$59	$105	$119	$333
Lotus	-	-	-	-	-
Mazda	$38	$95	$87	$101	$116
Mitsubishi	$48	$50	$49	$48	$134
Nissan	$576	$536	$705	$840	$1,058
Porsche	$2	$4	$6	$7	$9
Spyker	$0	$1	$2	$2	$4
Subaru	$33	$106	$214	$207	$203
Suzuki	$9	$12	$56	$56	$59
Tata	$10	$19	$31	$41	$51
Tesla	-	-	-	-	-
Toyota	$769	$1,631	$2,104	$2,560	$2,801
Volkswagen	$18	$46	$101	$127	$153
Total/Average	$5,254	$7,422	$9,887	$13,348	$15,038

Table VII-2n (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$214	$237	$305	$336
Daimler	$182	$210	$232	$236
Fiat	$1,337	$1,570	$1,627	$1,671
Ford	$2,522	$3,440	$3,537	$3,398
Geely	$53	$76	$86	$95
General Motors	$5,155	$5,638	$6,666	$7,336
Honda	$2,789	$2,730	$3,009	$2,500
Hyundai	$542	$582	$1,101	$878
Kia	$324	$340	$370	$361
Lotus	-	-	-	-
Mazda	$122	$294	$308	$299
Mitsubishi	$138	$145	$153	$155
Nissan	$1,264	$1,337	$1,741	$1,771
Porsche	$12	$19	$22	$23
Spyker	$5	$5	$6	$7
Subaru	$222	$218	$737	$600
Suzuki	$64	$68	$73	$79
Tata	$64	$77	$90	$103
Tesla	-	-	-	-
Toyota	$3,450	$4,069	$5,300	$5,215
Volkswagen	$178	$233	$320	$340
Total/Average	$18,637	$21,288	$25,682	$25,405

Table VII-2o
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Max Net Benefits (3% Discount Rate)
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$511	$613	$779	$927	$1,081
Daimler	$327	$431	$537	$721	$773
Fiat	$1,654	$1,608	$1,525	$1,989	$2,691
Ford	$1,466	$2,177	$2,101	$2,559	$3,141
Geely	$309	$489	$563	$716	$783
General Motors	$1,405	$1,495	$1,780	$2,403	$2,489
Honda	$1,555	$1,525	$1,777	$2,088	$2,139
Hyundai	$1,119	$1,121	$1,928	$2,087	$2,069
Kia	$1,170	$1,183	$1,686	$2,233	$2,510
Lotus	-	-	-	-	-
Mazda	$1,484	$1,650	$1,506	$1,627	$1,706
Mitsubishi	$1,335	$1,272	$1,301	$1,652	$3,796
Nissan	$1,768	$1,711	$1,992	$2,473	$2,563
Porsche	$293	$419	$516	$653	$714
Spyker	$309	$415	$519	$661	$1,023
Subaru	$1,172	$1,627	$2,680	$2,639	$2,556
Suzuki	$395	$513	$3,093	$3,016	$3,027
Tata	$326	$431	$572	$727	$758
Tesla	-	-	-	-	-
Toyota	$1,124	$1,341	$1,535	$1,627	$2,064
Volkswagen	$276	$393	$715	$863	$916
Total/Average	$1,265	$1,447	$1,651	$1,994	$2,227

Table VII-2o (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,398	$1,448	$1,508	$1,675
Daimler	$1,558	$1,608	$1,629	$1,738
Fiat	$2,690	$3,113	$3,409	$4,217
Ford	$3,239	$4,641	$4,775	$4,081
Geely	$1,000	$1,381	$1,437	$1,572
General Motors	$2,496	$2,678	$3,305	$4,232
Honda	$2,403	$2,426	$2,888	$2,834
Hyundai	$2,667	$2,677	$3,045	$3,051
Kia	$2,457	$2,431	$2,453	$2,502
Lotus	-	-	-	-
Mazda	$1,649	$2,582	$2,905	$2,804
Mitsubishi	$3,709	$3,651	$3,589	$3,502
Nissan	$2,675	$2,674	$3,439	$3,357
Porsche	$790	$1,284	$1,338	$1,454
Spyker	$1,073	$1,128	$1,194	$1,341
Subaru	$2,642	$2,675	$4,134	$3,782
Suzuki	$2,971	$3,074	$3,005	$3,025
Tata	$807	$879	$945	$1,132
Tesla	-	-	-	-
Toyota	$2,155	$2,363	$2,708	$3,014
Volkswagen	$959	$1,121	$1,492	$1,588
Total/Average	$2,315	$2,624	$3,043	$3,280

Table VII-2p
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Max Net Benefits (3% Discount Rate)
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$70	$81	$102	$119	$139
Daimler	$28	$36	$47	$67	$77
Fiat	$678	$624	$559	$717	$938
Ford	$1,119	$1,630	$1,508	$1,835	$2,243
Geely	$13	$21	$24	$30	$33
General Motors	$1,915	$2,150	$2,679	$3,678	$3,808
Honda	$928	$831	$937	$1,096	$1,146
Hyundai	$171	$170	$300	$322	$324
Kia	$115	$116	$170	$216	$240
Lotus	-	-	-	-	-
Mazda	$77	$95	$87	$95	$101
Mitsubishi	$50	$46	$46	$58	$134
Nissan	$787	$706	$794	$984	$1,046
Porsche	$4	$5	$6	$7	$8
Spyker	$1	$1	$2	$2	$4
Subaru	$92	$122	$195	$191	$186
Suzuki	$9	$11	$64	$62	$63
Tata	$19	$24	$33	$41	$44
Tesla	-	-	-	-	-
Toyota	$1,495	$1,640	$1,753	$1,878	$2,509
Volkswagen	$36	$57	$105	$127	$136
Total/Average	$7,606	$8,367	$9,411	$11,525	$13,178

Table VII-2p (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$180	$185	$221	$244
Daimler	$157	$169	$174	$176
Fiat	$977	$1,124	$1,176	$1,399
Ford	$2,314	$3,248	$3,289	$2,794
Geely	$42	$58	$61	$67
General Motors	$3,764	$4,008	$4,936	$6,450
Honda	$1,296	$1,303	$1,551	$1,581
Hyundai	$420	$431	$506	$513
Kia	$233	$233	$236	$244
Lotus	-	-	-	-
Mazda	$99	$160	$180	$172
Mitsubishi	$131	$129	$129	$127
Nissan	$1,102	$1,116	$1,452	$1,432
Porsche	$9	$15	$15	$16
Spyker	$4	$4	$4	$5
Subaru	$192	$195	$307	$283
Suzuki	$62	$64	$64	$65
Tata	$47	$52	$55	$64
Tesla	-	-	-	-
Toyota	$2,661	$2,895	$3,271	$3,646
Volkswagen	$141	$173	$234	$245
Total/Average	$13,829	$15,562	$17,861	$19,521

Table VII-2q
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Max Net Benefits (7% Discount Rate)
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$439	$552	$724	$801	$982
Daimler	$261	$371	$488	$600	$680
Fiat	$1,517	$1,503	$1,425	$1,868	$2,492
Ford	$1,302	$1,825	$1,870	$1,870	$2,529
Geely	$238	$423	$508	$584	$684
General Motors	$1,345	$1,496	$1,786	$2,187	$2,239
Honda	$1,030	$1,034	$1,180	$1,425	$1,514
Hyundai	$1,037	$1,041	$2,045	$2,147	$2,107
Kia	$514	$530	$695	$771	$1,141
Lotus	-	-	-	-	-
Mazda	$1,230	$1,608	$1,470	$1,586	$1,703
Mitsubishi	$1,282	$1,272	$1,195	$1,514	$2,289
Nissan	$1,388	$1,355	$1,943	$1,946	$2,183
Porsche	$221	$353	$461	$527	$615
Spyker	$238	$349	$464	$529	$924
Subaru	$572	$843	$2,161	$2,109	$2,069
Suzuki	$424	$574	$2,674	$2,606	$2,661
Tata	$254	$365	$511	$595	$653
Tesla	-	-	-	-	-
Toyota	$720	$879	$980	$1,051	$1,422
Volkswagen	$210	$333	$660	$742	$822
Total/Average	$1,038	$1,196	$1,420	$1,603	$1,835

Table VII-2q (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,271	$1,283	$1,305	$1,317
Daimler	$1,442	$1,460	$1,437	$1,402
Fiat	$2,514	$2,760	$2,768	$2,623
Ford	$2,481	$2,481	$2,446	$2,298
Geely	$879	$1,216	$1,233	$1,203
General Motors	$2,215	$2,412	$2,770	$2,668
Honda	$1,569	$1,557	$1,551	$1,484
Hyundai	$2,294	$2,255	$2,221	$2,085
Kia	$1,110	$1,159	$1,145	$1,154
Lotus	-	-	-	-
Mazda	$1,646	$1,607	$1,595	$1,531
Mitsubishi	$2,231	$2,195	$2,163	$2,045
Nissan	$2,426	$2,379	$2,331	$2,200
Porsche	$669	$1,124	$1,135	$1,102
Spyker	$946	$963	$985	$972
Subaru	$2,056	$2,023	$2,051	$1,956
Suzuki	$2,581	$2,635	$2,528	$2,334
Tata	$681	$709	$725	$752
Tesla	-	-	-	-
Toyota	$1,436	$1,567	$1,581	$1,539
Volkswagen	$844	$967	$1,300	$1,247
Total/Average	$1,873	$1,979	$2,080	$1,993

Table VII-2r
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Max Net Benefits (7% Discount Rate)
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$61	$73	$95	$103	$126
Daimler	$23	$31	$43	$56	$68
Fiat	$622	$583	$522	$674	$869
Ford	$994	$1,366	$1,342	$1,341	$1,806
Geely	$10	$18	$22	$25	$29
General Motors	$1,832	$2,151	$2,688	$3,348	$3,426
Honda	$614	$563	$623	$748	$811
Hyundai	$159	$158	$318	$331	$330
Kia	$51	$52	$70	$74	$109
Lotus	-	-	-	-	-
Mazda	$64	$92	$85	$92	$101
Mitsubishi	$48	$46	$42	$53	$81
Nissan	$617	$559	$775	$774	$891
Porsche	$3	$4	$5	$6	$7
Spyker	$1	$1	$2	$2	$3
Subaru	$45	$63	$157	$153	$151
Suzuki	$9	$12	$55	$54	$55
Tata	$15	$21	$30	$33	$38
Tesla	-	-	-	-	-
Toyota	$958	$1,075	$1,119	$1,213	$1,729
Volkswagen	$27	$48	$97	$109	$122
Total/Average	$6,152	$6,918	$8,090	$9,189	$10,750

Table VII-2r (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$164	$164	$191	$192
Daimler	$146	$154	$154	$142
Fiat	$913	$997	$955	$870
Ford	$1,772	$1,737	$1,685	$1,573
Geely	$37	$51	$52	$51
General Motors	$3,339	$3,611	$4,137	$4,066
Honda	$846	$836	$833	$828
Hyundai	$361	$363	$369	$351
Kia	$105	$111	$110	$113
Lotus	-	-	-	-
Mazda	$99	$100	$99	$94
Mitsubishi	$79	$78	$78	$74
Nissan	$999	$992	$984	$938
Porsche	$8	$13	$13	$12
Spyker	$3	$3	$3	$3
Subaru	$150	$148	$152	$146
Suzuki	$54	$55	$53	$50
Tata	$40	$42	$42	$43
Tesla	-	-	-	-
Toyota	$1,774	$1,919	$1,909	$1,862
Volkswagen	$124	$149	$204	$192
Total/Average	$11,010	$11,521	$12,024	$11,600

Table VII-2s
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Total Cost = Total Benefit (3% Discount Rate)
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$522	$635	$801	$894	$1,053
Daimler	$338	$448	$559	$688	$746
Fiat	$1,677	$1,608	$1,525	$2,015	$2,685
Ford	$1,468	$2,171	$2,087	$2,621	$3,210
Geely	$320	$505	$585	$677	$761
General Motors	$1,416	$1,495	$1,781	$2,403	$2,464
Honda	$1,433	$1,401	$1,558	$1,757	$1,951
Hyundai	$1,157	$1,158	$1,965	$2,072	$2,058
Kia	$1,170	$1,183	$1,686	$1,935	$2,288
Lotus	-	-	-	-	-
Mazda	$1,495	$1,609	$1,471	$1,591	$1,795
Mitsubishi	$1,342	$1,272	$1,344	$1,613	$3,796
Nissan	$1,872	$1,809	$2,074	$2,576	$2,676
Porsche	$298	$441	$538	$615	$686
Spyker	$320	$437	$541	$623	$1,001
Subaru	$1,172	$1,627	$2,680	$2,639	$2,556
Suzuki	$406	$541	$3,103	$3,026	$3,037
Tata	$337	$453	$594	$688	$730
Tesla	-	-	-	-	-
Toyota	$1,107	$1,380	$1,616	$1,713	$2,174
Volkswagen	$287	$415	$737	$830	$894
Total/Average	$1,258	$1,450	$1,652	$1,986	$2,247

Table VII-2s (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,359	$1,475	$1,574	$1,631
Daimler	$1,519	$1,630	$1,690	$1,699
Fiat	$2,674	$3,156	$3,489	$4,176
Ford	$3,269	$4,691	$4,835	$4,188
Geely	$961	$1,408	$1,508	$1,528
General Motors	$2,461	$2,712	$3,366	$4,194
Honda	$2,329	$2,347	$2,663	$2,667
Hyundai	$2,667	$2,627	$5,923	$4,589
Kia	$2,249	$2,352	$2,372	$2,200
Lotus	-	-	-	-
Mazda	$1,649	$2,466	$2,788	$2,616
Mitsubishi	$3,709	$3,651	$3,759	$3,568
Nissan	$2,667	$2,665	$3,534	$3,287
Porsche	$751	$1,311	$1,404	$1,415
Spyker	$1,034	$1,155	$1,260	$1,297
Subaru	$2,603	$2,620	$4,134	$3,782
Suzuki	$2,980	$3,105	$3,080	$2,981
Tata	$769	$907	$1,011	$1,088
Tesla	-	-	-	-
Toyota	$2,202	$2,836	$2,946	$3,148
Volkswagen	$926	$1,143	$1,558	$1,549
Total/Average	$2,328	$2,729	$3,155	$3,372

Table VII-2t
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Total Cost = Total Benefit (3% Discount Rate)
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$72	$84	$105	$115	$136
Daimler	$29	$37	$49	$64	$74
Fiat	$687	$624	$559	$727	$936
Ford	$1,121	$1,626	$1,498	$1,879	$2,293
Geely	$13	$21	$25	$29	$32
General Motors	$1,930	$2,151	$2,680	$3,679	$3,769
Honda	$855	$763	$822	$923	$1,046
Hyundai	$177	$175	$306	$319	$322
Kia	$115	$116	$170	$187	$218
Lotus	-	-	-	-	-
Mazda	$77	$93	$85	$93	$106
Mitsubishi	$50	$46	$48	$57	$134
Nissan	$833	$746	$827	$1,025	$1,092
Porsche	$4	$5	$6	$7	$8
Spyker	$1	$2	$2	$2	$4
Subaru	$92	$122	$195	$191	$186
Suzuki	$9	$12	$64	$63	$63
Tata	$19	$26	$34	$39	$42
Tesla	-	-	-	-	-
Toyota	$1,473	$1,689	$1,845	$1,977	$2,643
Volkswagen	$37	$60	$108	$122	$133
Total/Average	$7,596	$8,398	$9,428	$11,496	$13,236

Table VII-2t (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$175	$188	$231	$237
Daimler	$153	$172	$181	$172
Fiat	$971	$1,140	$1,204	$1,385
Ford	$2,335	$3,284	$3,330	$2,866
Geely	$40	$59	$64	$65
General Motors	$3,710	$4,059	$5,028	$6,391
Honda	$1,256	$1,260	$1,430	$1,488
Hyundai	$420	$423	$984	$772
Kia	$213	$225	$228	$215
Lotus	-	-	-	-
Mazda	$99	$153	$173	$161
Mitsubishi	$131	$129	$135	$130
Nissan	$1,099	$1,112	$1,492	$1,402
Porsche	$9	$15	$16	$16
Spyker	$4	$4	$4	$5
Subaru	$189	$191	$307	$283
Suzuki	$62	$65	$65	$64
Tata	$45	$53	$59	$62
Tesla	-	-	-	-
Toyota	$2,720	$3,474	$3,559	$3,809
Volkswagen	$136	$176	$245	$239
Total/Average	$13,766	$16,182	$18,734	$19,759

Table VII-2u
Estimated Incremental Costs or Fines over Adjusted Baseline
Average Cost per Vehicle (2009 Dollars)
Total Cost = Total Benefit (7% Discount Rate)
Light Trucks

Manufacturer	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Aston Martin	-	-	-	-	-
BMW	$527	$635	$801	$894	$1,053
Daimler	$349	$448	$559	$688	$746
Fiat	$1,688	$1,608	$1,525	$2,015	$2,685
Ford	$1,468	$2,171	$2,087	$2,621	$3,210
Geely	$331	$505	$585	$677	$761
General Motors	$1,422	$1,495	$1,781	$2,403	$2,464
Honda	$1,433	$1,401	$1,558	$1,757	$1,951
Hyundai	$1,176	$1,178	$1,984	$2,084	$2,086
Kia	$1,170	$1,183	$1,686	$1,935	$2,225
Lotus	-	-	-	-	-
Mazda	$1,506	$1,609	$1,471	$1,591	$1,795
Mitsubishi	$1,353	$1,272	$1,344	$1,613	$3,796
Nissan	$1,876	$1,813	$2,090	$2,582	$2,677
Porsche	$309	$441	$538	$615	$686
Spyker	$331	$437	$541	$623	$1,001
Subaru	$1,172	$1,627	$2,680	$2,639	$2,556
Suzuki	$417	$541	$3,103	$3,026	$3,037
Tata	$348	$453	$594	$688	$730
Tesla	-	-	-	-	-
Toyota	$1,132	$1,396	$1,632	$1,728	$2,145
Volkswagen	$293	$415	$737	$830	$894
Total/Average	$1,265	$1,454	$1,657	$1,990	$2,241

Table VII-2u (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$1,359	$1,475	$1,574	$1,631
Daimler	$1,519	$1,630	$1,690	$1,699
Fiat	$2,674	$3,156	$3,489	$4,176
Ford	$3,269	$4,707	$4,851	$4,187
Geely	$961	$1,408	$1,508	$1,528
General Motors	$2,461	$2,712	$3,366	$4,194
Honda	$2,329	$2,345	$2,668	$2,667
Hyundai	$2,667	$2,627	$5,923	$4,589
Kia	$2,186	$2,288	$2,405	$2,200
Lotus	-	-	-	-
Mazda	$1,649	$2,466	$2,788	$2,616
Mitsubishi	$3,709	$3,651	$3,759	$3,568
Nissan	$2,665	$2,706	$3,548	$3,370
Porsche	$751	$1,311	$1,404	$1,415
Spyker	$1,034	$1,155	$1,260	$1,297
Subaru	$2,603	$2,620	$4,134	$3,782
Suzuki	$2,980	$3,105	$3,080	$2,981
Tata	$769	$907	$1,011	$1,088
Tesla	-	-	-	-
Toyota	$2,177	$2,836	$2,965	$3,165
Volkswagen	$926	$1,143	$1,558	$1,549
Total/Average	$2,322	$2,729	$3,161	$3,377

Table VII-2v
Estimated Incremental Costs or Fines over Adjusted Baseline
Total Incremental Costs in Millions (2009 Dollars)
Total Cost = Total Benefit (7% Discount Rate)
Light Trucks

Manufacturer	**MY 2017**	**MY 2018**	**MY 2019**	**MY 2020**	**MY 2021**
Aston Martin	-	-	-	-	-
BMW	$73	$84	$105	$115	$136
Daimler	$30	$37	$49	$64	$74
Fiat	$692	$624	$559	$727	$936
Ford	$1,121	$1,626	$1,498	$1,879	$2,293
Geely	$14	$21	$25	$29	$32
General Motors	$1,937	$2,151	$2,680	$3,679	$3,769
Honda	$855	$763	$822	$923	$1,046
Hyundai	$180	$178	$309	$321	$326
Kia	$115	$116	$170	$187	$212
Lotus	-	-	-	-	-
Mazda	$78	$93	$85	$93	$106
Mitsubishi	$51	$46	$48	$57	$134
Nissan	$835	$747	$833	$1,027	$1,092
Porsche	$4	$5	$6	$7	$8
Spyker	$1	$2	$2	$2	$4
Subaru	$92	$122	$195	$191	$186
Suzuki	$9	$12	$64	$63	$63
Tata	$20	$26	$34	$39	$42
Tesla	-	-	-	-	-
Toyota	$1,506	$1,708	$1,864	$1,994	$2,607
Volkswagen	$38	$60	$108	$122	$133
Total/Average	$7,651	$8,421	$9,456	$11,518	$13,199

Table VII-2v (continued)

Manufacturer	**MY 2022**	**MY 2023**	**MY 2024**	**MY 2025**
Aston Martin	-	-	-	-
BMW	$175	$188	$231	$237
Daimler	$153	$172	$181	$172
Fiat	$971	$1,140	$1,204	$1,385
Ford	$2,335	$3,295	$3,342	$2,866
Geely	$40	$59	$64	$65
General Motors	$3,710	$4,059	$5,028	$6,391
Honda	$1,256	$1,259	$1,433	$1,488
Hyundai	$420	$423	$984	$772
Kia	$207	$219	$231	$215
Lotus	-	-	-	-
Mazda	$99	$153	$173	$161
Mitsubishi	$131	$129	$135	$130
Nissan	$1,098	$1,129	$1,498	$1,437
Porsche	$9	$15	$16	$16
Spyker	$4	$4	$4	$5
Subaru	$189	$191	$307	$283
Suzuki	$62	$65	$65	$64
Tata	$45	$53	$59	$62
Tesla	-	-	-	-
Toyota	$2,689	$3,474	$3,582	$3,830
Volkswagen	$136	$176	$245	$239
Total/Average	$13,729	$16,203	$18,779	$19,815

Indirect Costs

Indirect Cost Multiplier Changes

As discussed in greater detail below, the agencies have revised the markups used to estimate indirect costs. The first change was to adjust ICM values based on a change in the retail price equivalent (RPE) value to which they are normalized. Previously, the ICM values were normalized to a single year value of 1.46, which was recommended in a study conducted by RTI.[249] The agencies have revised the normalization to 1.50, which represents the historical average retail price equivalent (RPE). This was done by applying a factor of .50/.46 to all indirect cost elements. The second change was to re-consider the markup factors and the data used to generate them. The ICM values for low and medium complexity technologies are now based solely on modified Delphi estimates. 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 have reconsidered this approach and are no longer applying learning to ICMs, except the warranty component, which are influenced by the learned value of direct 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. The collective effect of these changes is to increase the ICM factors applied to technologies.

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

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[249] 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.

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. 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, the agencies have 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

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

To develop the ICMs from the RPE multipliers adjustment factors were developed 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.[250] 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 proposed rulemaking, 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 further analysis by the EPA-NHTSA team related to the derivation of the ICM values. The second change was implemented in response to both further consideration by the agencies and public feedback that learning effects should not be applied to indirect costs through the multiplicative approach that was being used.

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[250] 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 .

Regarding the first change, in the original work done under contract to EPA by RTI International,[251] EPA experts used a consensus approach to determine the impact of three new technologies on the indirect costs of manufacturers. Subsequent to that work, EPA experts used a somewhat different approach to estimate the costs for three different technologies using 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 different ICM aggregate and individual element values. This effort is detailed in a memorandum contained in the docket for this rule.[252] For the MY 2012-2016 GHG/CAFE rulemaking, the original RTI values were averaged with the modified-Delphi values to arrive at the final ICMs for low and medium complexity technologies, RTI values were used for high complexity level 1 technologies, and modified-Delphi values were used for high complexity level 2 technologies.

Recently, EPA and NHTSA have examined the elements of the ICMs more closely and determined that the technologies that were analyzed in the original RTI study are not as representative of the broad array of low and medium complexity technologies as the technologies that were examined in the modified-Delphi study, and that the values in the Delphi study better estimate the markup cost elements for low and medium complexity technologies. 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. In comparison, the modified-Delphi study used passive aerodynamic improvements as the representative low complexity technology and turbocharging with downsizing as the representative medium complexity technology. Consequently, , the modified-Delphi values are being used alone as the basis for ICMs for low and medium complexity technologies. NHTSA and EPA technical staffs have also re-examined the selection of technology complexity category for each of the technologies to better align the unexamined technologies to the reference technologies for which ICM values were estimated. The resulting designations together with the associated reference technologies are shown in Table VII-3

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[251] 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.

[252] Helfand, Gloria, and Todd Sherwood, "Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies," August 2009.

Table VII-3

Technology Designations by ICM Category, with Reference Technology

Low Technology ***Passive Aerodynamic Improvements.***	**Medium Technology** ***Engine Turbo Downsizing***	**High Tech 1** ***Hybrid Electric Vehicle***	**High Tech 2** ***Plug-in Hybrid Electric Vehicle***
Passive Aerodynamic Improv.	6-speed DCTs	Strong Hybrids	PHEV battery packs
Lubricant improvements	Mass Reduction 15-20%	PHEV and EV chargers	All Electric vehicles
Mass Reductions 3-10%	Turbocharging	PHEV non battery components	
Aggressive Shift Logic	Cylinder deactivation		
Engine Friction Reduction	VVT-dual cam phasing & Discrete variable valve lift		
Engine Downsizing	8-speed auto and DCT transmissions		
6 speed auto transmissions	12 volt start-stop systems		
Low Drag Brakes	Active aerodynamic improvements		
Electro-hydraulic power steering	Converting OHV/SOHC to DOHC		
Electric power steering	Gasoline direct injection		
WT intake or coupled	Turbo downsizing		
Improved accessories	Turbo downsizing +EGR		
	Advanced Diesel		

Many of the basic technologies listed in Table VII-3 have variations that share the same complexity designation and ICM estimate. Table VII-4 lists each of the technologies used in the VOLPE model together with both their ICM category and the year through which the short term ICM will be applied. Note that the number behind each ICM Category designation refers to the source of the ICM estimate, with 1 indicating the consensus panel and 2 indicating the modified Delphi panel.

Table VII-4

ICM categories and Short Term ICM Schedules for CAFE Technologies

Technology	**ICM Category**	**Short Term Through**
Low Friction Lubricants - Level 1	Low2	2018
Engine Friction Reduction - Level 1	Low2	2018
Low Friction Lubricants and Engine Friction Reduction - Level 2	Low2	2024
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	Low2	2018
Discrete Variable Valve Lift (DVVL) on SOHC	Medium2	2018
Cylinder Deactivation on SOHC	Medium2	2018
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	Low2	2018
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	Medium2	2018
Discrete Variable Valve Lift (DVVL) on DOHC	Medium2	2018

Continuously Variable Valve Lift (CVVL)	Medium2	2018
Cylinder Deactivation on DOHC	Medium2	2018
Stoichiometric Gasoline Direct Injection (GDI)	Medium2	2018
Cylinder Deactivation on OHV	Medium2	2018
Variable Valve Actuation - CCP and DVVL on OHV	Medium2	2018
Stoichiometric Gasoline Direct Injection (GDI) on OHV	Medium2	2018
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement - Turbo	Medium2	2018
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement - Downsize	Medium2	2018
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement -Turbo	Medium2	2018
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement - Downsize	Medium2	2018
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement - Turbo	Medium2	2018
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement - Downsize	Medium2	2018
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement - Turbo	Medium2	2024
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement - Downsize	Medium2	2018
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement - Turbo	Medium2	2024
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement - Downsize	Medium2	2018
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement - Turbo	Medium2	2024
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement - Downsize	Medium2	2018
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement - Turbo	Medium2	2024
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement - Downsize	Medium2	2018
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement - Turbo	Medium2	2024
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement - Downsize	Medium2	2018
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement - Turbo	Medium2	2024
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement - Downsize	Medium2	2018
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement - Turbo	Medium2	2024
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement - Downsize	Medium2	2018
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement - Turbo	Medium2	2024
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement - Downsize	Medium2	2018
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement - Turbo	Medium2	2024
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement - Downsize	Medium2	2018
Advanced Diesel - Small Displacement	Medium2	2024
Advanced Diesel - Medium Displacement	Medium2	2024
Advanced Diesel - Large Displacement	Medium2	2024
6-Speed Manual/Improved Internals	Low2	2018
Improved Auto. Trans. Controls/Externals	Low2	2018
6-Speed Trans with Improved Internals (Auto)	Low2	2018
6-speed DCT	Medium2	2018
8-Speed Trans (Auto or DCT)	Medium2	2018
High Efficiency Gearbox w/ dry sump (Auto or DCT)	Low2	2024
Shift Optimizer	Low2	2024
Electric Power Steering	Low2	2018
Improved Accessories - Level 1	Low2	2018
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	Low2	2024
12V Micro-Hybrid (Stop-Start)	Medium2	2018
Integrated Starter Generator	High1	2018
Strong Hybrid (Powersplit or 2-Mode) - Level 1 – Battery	High1	2024
Strong Hybrid (Powersplit or 2-Mode) - Level 1 - Non-Battery	High1	2018
Conversion from SHEV1 to SHEV2	HIgh1	2018
Strong Hybrid (P2 Parallel or 2-Mode) - Level 2 – Battery	High1	2024
Strong Hybrid (P2 Parallel or 2-Mode) - Level 2 - Non-Battery	High1	2018

Plug-in Hybrid - 20 mi range – Battery	High2	2024
Plug-in Hybrid - 20 mi range - Non-Battery	High1	2018
Plug-in Hybrid - 40 mi range – Battery	High2	2024
Plug-in Hybrid - 40 mi range - Non-Battery	High1	2018
Electric Vehicle (Early Adopter) - 75 mile range – Battery	High2	2024
Electric Vehicle (Early Adopter) - 75 mile range - Non-Battery	High2	2024
Electric Vehicle (Early Adopter) - 100 mile range – Battery	High2	2024
Electric Vehicle (Early Adopter) - 100 mile range - Non-Battery	High2	2024
Electric Vehicle (Early Adopter) - 150 mile range – Battery	High2	2024
Electric Vehicle (Early Adopter) - 150 mile range - Non-Battery	High2	2024
Electric Vehicle (Broad Market) - 150 mile range – Battery	High2	2024
Electric Vehicle (Broad Market) - 150 mile range - Non-Battery	High2	2024
Fuel Cell Vehicle	High2	2024
Charger-PHEV20	High1	2024
Charger-PHEV40	High1	2024
Charger-EV	High1	2024
Charger Labor	None	2024
Mass Reduction - Level 1	Low2	2018
Mass Reduction - Level 2	Low2	2018
Mass Reduction - Level 3	Low2	2018
Mass Reduction - Level 4	Low2	2018
Mass Reduction - Level 5	Low2	2018
Low Rolling Resistance Tires - Level 1	Low2	2018
Low Rolling Resistance Tires - Level 2	Low2	2024
Low Rolling Resistance Tires - Level 3	Low2	2024
Low Drag Brakes	Low2	2018
Secondary Axle Disconnect	Low2	2018
Aero Drag Reduction, Level 1	Low2	2018
Aero Drag Reduction, Level 2	Medium2	2024

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 1.50 to better 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 at approximately 1.50. The agencies believe that using the historical average value would result in ICMs that better estimate the future values. Therefore, ICMs in this proposed rulemaking were adjusted to reflect this average level. As a result, the ICM values for the High 1 and High 2 complexity technologies have also changed.

Table VII-5 shows both the ICM values used in the MYs 2012-2016 final rule and the new ICM values used for the analysis supporting these proposed 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, the long term ICM is applied to direct costs.

Table VII-5 Indirect Cost Multipliers Used in this Analysis[a]

	2012-2016 Rule		This Proposal	
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. In the past, ICMs have been applied as pure multiplicative factors. 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 because of learning, 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 are composed of a number of costs, such as facility-related costs, electricity, etc., that are not affected by learning, the agencies do not believe ICMs should be applied 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 been modified for this proposal and is more complex. First the year in which the direct manufacturing costs are considered "valid" is established. 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. The costs in that year are 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 VII-6). 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 VII-6 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

The impact of learning on direct costs, together with the eventual application of long-term ICMs, causes the effective ICM based markup to differ from the initial ICM on a year-by-year basis. An example of how this occurs is provided in Table VII-7[253]. This table traces the impact of learning on direct costs and its implications for both total costs and the derived ICM based markup. Direct costs are assigned a value of 1 to simplify the illustrative analysis and to use the same basis as for ICMs (in an ICM markup factor, the value of direct costs is represented by 1 while the value of indirect costs is represent by the fraction of 1 to the right of the decimal.) The table examines the impacts of these factors on Turbo downsized engines, one of the more prevalent CAFE technologies.

Table VII-7

Derived Annual ICMs for Turbo Downsized Engines

Year	Learning Schedule #11	Direct Costs	Other Indirect Costs	Warranty	Total Costs	Effective ICM Based Markup Factor
2010	0.03					
2011	0.03					
2012	0.03	1	0.3427	0.0446	1.3872	1.387
2013	0.03	0.97	0.3427	0.0432451	1.3559	1.398
2014	0.03	0.9409	0.3427	0.0419478	1.3255	1.409
2015	0.03	0.912673	0.3427	0.0406893	1.2960	1.420
2016	0.03	0.8852928	0.3427	0.0394687	1.2674	1.432
2017	0.02	0.867587	0.3427	0.0386793	1.2489	1.440
2018	0.02	0.8502352	0.3427	0.0379057	1.2308	1.448
2019	0.02	0.8332305	0.2587	0.0310	1.1229	1.348
2020	0.02	0.8165659	0.2587	0.0303882	1.1056	1.354
2021	0.02	0.8002346	0.2587	0.0297805	1.0887	1.360
2022	0.02	0.7842299	0.2587	0.0291849	1.0721	1.367
2023	0.02	0.7685453	0.2587	0.0286012	1.0558	1.374

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[253] The table illustrates the learning process from the base year consistent with the direct cost estimate obtained by the agencies. It is a mature technology well into the flat portion of the learning curve. Note however, that the costs actually applied in this rulemaking will begin with the 2017 model year.

2024	0.02	0.7531744	0.2587	0.0280291	1.0399	1.381
2025	0.02	0.7381109	0.2587	0.0274686	1.0243	1.388
2026	0.01	0.7307298	0.2587	0.0271939	1.0166	1.391
2027	0.01	0.7234225	0.2587	0.0269219	1.0090	1.395
2028	0.01	0.7161883	0.2587	0.0266527	1.0015	1.398
2029	0.01	0.7090264	0.2587	0.0263862	0.9941	1.402
2030	0.01	0.7019361	0.2587	0.0261223	0.9867	1.406
Average ICM 2017 through 2030 =						1.389

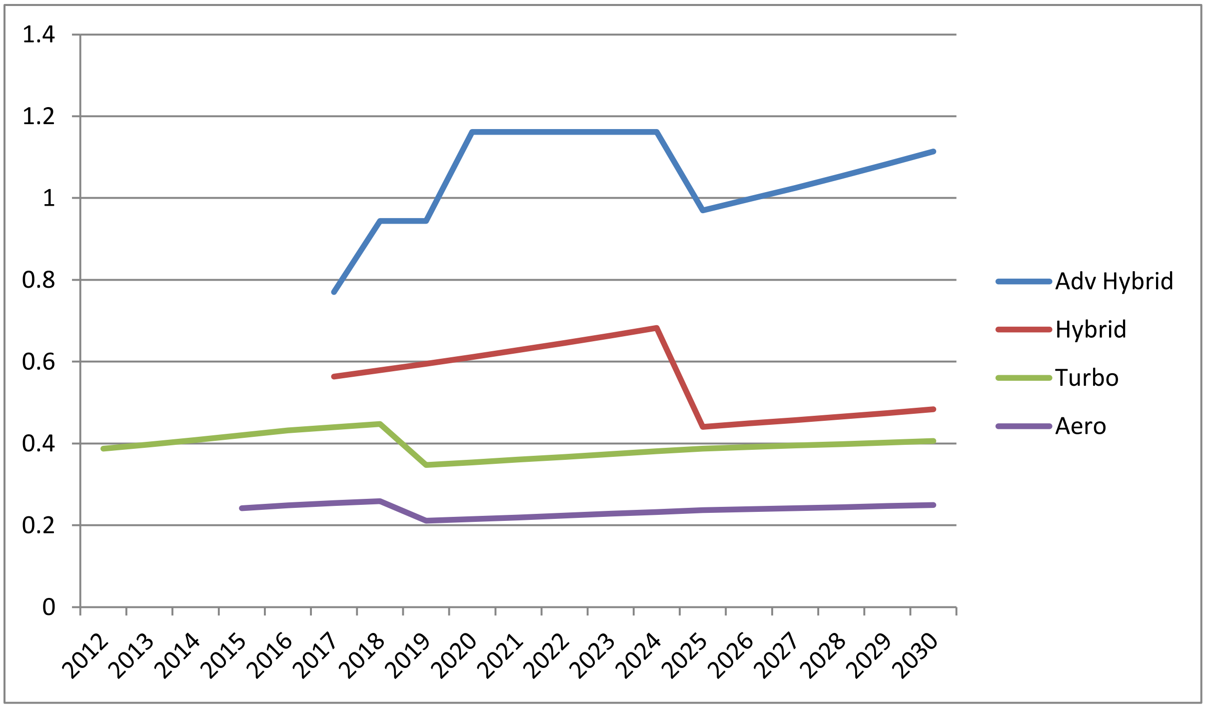
The second column of Table VII-7 lists the learning schedule that is applied to turbocharging and downsizing. Turbocharging and downsizing is a mature technology so the learning schedule captures the relatively flat portion of the learning curve that occurs after the larger decreases have already reduced direct costs. The cost basis for Turbocharging and downsizing in the analysis was effective in 2012, so this is the base year for this calculation when direct costs are set to 1. The third column shows the progressive decline in direct costs as the learning schedule in column 2 is applied to direct costs. Column 4 contains the value of all indirect costs except warranty. Turbocharging and downsizing are a medium complexity technology so this value is taken from the Medium row of Table VII-6. The initial value in 2012 is the near term value, which is used through 2018. During this time, these indirect costs are not impacted by learning and they remain constant. Beginning in 2019, the long-term ICM from Table VII-6 is applied. The fifth column contains warranty costs. As previously mentioned, these costs are considered to be impacted by learning like direct costs, so they decline steadily until the long-term ICM is applied in 2019, at which point they drop before continuing their gradual decline. In the sixth column, direct and indirect costs are totaled. The results show an overall decline in total costs of roughly 30% during this 14 year period. The last column shows the effective ICM based markup, which is derived by dividing total costs by direct costs. Over this period, the derived ICM based markup rose from the initial short term ICM level of 1.39 to 1.45 in 2018. It then declined to 1.35 in 2019 when the long-term ICM was applied to the learned down direct cost. Over the remaining years, the ICM based markup gradually rises back up to 1.41 as learning continues to decrease direct costs.

There are thus two somewhat offsetting processes that impact the effective ICM based markup. The first is the learning curve which reduces direct costs, which raises the derived ICM based markup. As noted previously learning reflects learned efficiencies in assembly methods as well as reduced parts and materials costs. The second is the application of a long-term ICM, which reduces the derived ICM based markup. This represents the reduced burden needed to maintain new technologies once they are fully developed. In this case, the two processes largely offset one another and produce an average ICM based markup over this 14 year period that roughly equals the original short term ICM.

Figure VII-1 illustrates this process for each of the 4 representative technologies that are used to estimate ICM values for each of the complexity categories. As with the turbocharging and downsizing, aerodynamic improvements and strong hybrid vehicles show a gradual increase in the effective ICM based markup through the point where the long-term ICM is applied. At that time, the effective markup declines, and then begins a gradual rise. The advanced hybrid ICM behaves somewhat differently because the technology is not as mature and, as a result, experiences a greater change in the learning value that influences the effective markup value. This produces a step-up in markup values concurrent with each learning step, followed by a decline when the long-term ICM is applied. After that, the effective markup value begins a gradual rise as more moderate learning is applied to reflect its shift to a mature technology. Note that, as with the turbocharging and downsizing example above, for the aerodynamic improvements and mild hybrid technologies the offsetting processes of learning and long-term ICMs result in an average effective ICM based markup over the full time frame that is roughly equal to the initial short-term ICM. However, the advanced hybrid markup rose to a level that is significantly higher than the initial ICM. This is a direct function of the rapid learning schedule applied in the early years to this developing technology. Brand new technologies might thus be expected to have lifetime effective ICM based markups that exceed their initial ICMs, while more mature technologies are more likely to experience markups over their remaining life span that more closely approximate their initial ICMs.

Figure VII-1

Derived ICM Based Markups for Advanced Hybrid Technologies (PHEV Battery Packs and EVs), Hybrids, Turbocharging and Downsizing, and Passive Aerodynamic Improvements



ICMs for these 4 technologies determine the indirect cost markup rate for all technologies used in the CAFE model analysis that supports this proposal. However, the overall impact on costs is also a function of the relative incidence of each of the 88 technologies shown in Table V11-4, which are estimated to have ICMs similar to one of these 4 technologies. The net impact on costs of these ICMs is also influenced by the learning curve that is appropriate to each technology, creating numerous different and unique ICM based markup paths. The average effective markup applied by the CAFE model is also a function of each technologies direct cost - since ICMs are applied to direct costs, the measured indirect cost is proportionately higher for any given ICM when direct costs are higher. The average ICM based markup applied to the fleet for any given model year is calculated as follows:

Where: D = learned direct cost of each technology

A = application rate for each technology

ICM = average ICM applied to each technology

n=1,88

The VOLPE model predicts technology application rates assuming that manufacturers will apply technologies to meet standards in a logical fashion based on estimated costs and benefits. The application rates will thus be different for each model year and for each alternative scenario that is examined. To illustrate the overall impact of ICMs on total technology costs, NHTSA has calculated the weighted average ICM based markup across all technologies for the Preferred alternative[254]. This was done separately for each vehicle type and then aggregated based on the predicted sales of each vehicle type used in the model. The results are shown in Table VII-8.

Table VII-8

Average ICM Based Markup Applied in Preferred Alternative Scenario

Model Year	Passenger Cars	Light Trucks	All Vehicles
2017	0.34	0.28	0.31
2018	0.34	0.29	0.31
2019	0.29	0.23	0.26
2020	0.30	0.24	0.27
2021	0.30	0.25	0.28

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[254] For each alternative, this rulemaking examined numerous scenarios based on different assumptions and these assumptions could have some influence on the relative frequency of selection of different technologies, which in turn could affect the average ICM. The scenario examined here assumes a 3% discount rate, a 1 year payback period, real world application of expected fines, and reflects expected voluntary over-compliance by manufacturers.

2022	0.31	0.25	0.29
2023	0.37	0.25	0.32
2024	0.47	0.25	0.38
2025	0.43	0.24	0.35
All Years	0.35	0.25	0.31

The effective ICM based markups in table VII-8 are derived in a manner consistent with the way that the RPE is measured, that is, they reflect the combined influences of direct cost learning and changes in indirect cost requirements weighted by both the incidence of each technologies adaptation and the relative direct cost of each technology. The results indicate generally higher ICMs for passenger cars than for light trucks. This is a function of the technologies that are estimated to be adopted for each respective vehicle type, especially in the later years when hybrids and electric vehicles become more prevalent in the passenger car fleet. The influence of these advanced vehicles is driven primarily by their direct costs, which greatly outweigh the costs of other technologies. This results in the application of much more weight to their higher ICMs. This is most notable in 2024 and 2025 for passenger cars, when electric vehicles begin to enter the fleet. The average ICM jumps 0.10 in 2024 primarily due to these vehicles. It immediately drops 0.03 in 2025 because both an additional application of 20% learning to the direct cost of these vehicles (which reduces their relative weight), and the long term ICM becomes effective in that year (which decreases the absolute ICM factor). Both influences occur one year after these vehicles begin to enter the fleet due to CAFE requirements.

The ICM based markups also change over time, again, reflecting the different mix of technologies that are present during the earlier years, but that are often replaced with more expensive technologies in the later years. Across all model years, the wide ranging application of diverse technologies required to meet CAFE standards produces an average ICM of approximately 1.3.

There is some level of uncertainty surrounding both the ICM and RPE markup factors. The ICM estimates used in this proposal group all technologies into four broad categories (low, medium, and two levels of high complexity) and applies a single ICM actor to all of the individual technologies within each of the categories. This simplification assumes that the 4 technologies for which ICM values were estimated are representative of the other technologies which were not examined (see table VII-4 above). The accuracy of the estimates is affected by how appropriately each technology is categorized with the representative technology, and if the ICMs for that representative technology are near the midpoint of the real ICMs of all the technologies that they represent. 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, there is uncertainty because the ICM estimates were developed using panel estimates rather than empirical data, and they have not 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 simple technologies, or understates them for advanced technologies.

Recognizing this uncertainty, NHTSA has conducted a sensitivity analysis substituting the RPE for the ICMs used in the central analysis to mark up direct manufacturing costs. This serves as a measure of the potential impact on total costs of using ICMs compared to the RPE. As noted previously, the RPE is the ratio of aggregate retail prices to aggregate direct manufacturing costs. The ratio already reflects the mixture of learned costs of technologies at various stages of maturity. Therefore, the RPE is applied directly to the learned direct cost for each technology in each year. This was done for the same Preferred Alternative scenario used in the above analysis of average ICMs (see footnote 6). The results are shown in Table VII-9.

Table VII-9

Relative Impacts of Applying ICMs vs. RPE to Determine Indirect Costs

	Incremental Technology Total Costs (Millions$)		**Ratios**		Difference
Model Year	**ICM**	**1.5 RPE**	**RPE/ICM**	**ICM/RPE**	**RPE-ICM**
2017	$2,490	$3,433	1.38	0.73	0.27
2018	$4,894	$6,640	1.36	0.74	0.26
2019	$8,313	$10,601	1.28	0.78	0.22
2020	$11,930	$15,333	1.29	0.78	0.22
2021	$15,905	$20,345	1.28	0.78	0.22
2022	$18,056	$23,220	1.29	0.78	0.22
2023	$22,339	$28,233	1.26	0.79	0.21
2024	$29,249	$36,350	1.24	0.80	0.20
2025	$32,666	$40,956	1.25	0.80	0.20
Total	$145,841	$185,111	1.27	0.79	0.21

Application of an RPE instead of ICMs would result in technology cost increases averaging roughly 27% higher over the MY2012-MY2025 timeframe. The difference is generally higher in earlier model years because in those years the more cost effective technologies are incorporated into the fleet. These tend to be low complexity technologies with lower ICMs. In later years, the more expensive technologies are applied, including more hybrid and electric vehicles. These tend to be more complex technologies, and the average ICM based markup thus increases to a level closer to the average RPE. This, in turn, diminishes the difference between the technology estimates; in this case from a 38% increase in MY2017 to a 25% increase in MY 2025. Conversely, these differences represent declines in costs relative to an RPE basis ranging from 27% in 2017 to 20% in 2025, and averaging 21% over the 2017-2025 model years. Note that there are two different reasons for these differences. The first is the direct impact of applying a higher retail markup. The second is an indirect effect resulting from the impact that these differing markups have on the order of the selection of technologies, which can change as different direct cost levels interact with altered retail markups, shifting their relative overall effectiveness.

The relative impacts of ICMs may vary somewhat by scenario, but in this case, the application of ICMs produces total technology cost estimates that are roughly 20% lower than those that would result from applying a single RPE factor to all technologies. The impacts of applying an RPE to other scenarios can be found in the Sensitivity Analysis Chapter.

Learning Curves:

NHTSA applies estimates of learning curves to the various technologies that will be used to meet CAFE standards. Learning curves reflect the impact of experience and volume on the cost of production. As manufacturers gain experience through production, they refine production techniques, raw material and component sources, and assembly methods to maximize efficiency and reduce production costs. Typically, learning curves reflect initial learning rates that are relatively high, followed by slower learning as the easier improvements are made and production efficiency peaks. This eventually produces an asymptotic shape to the learning curve as small percent decreases are applied to gradually declining cost levels (see Figure VII-2).

Learning Applications in Previous Rulemakings

Over previous rulemakings, NHTSA has estimated the impact of learning using a variety of methods as our thinking about learning has evolved due to research, public comment, and methodology development. In the 2008 NPRM, working in conjunction with the EPA, NHTSA applied learning factors to technology costs for the first time. The factors were developed using three parameters which include learning threshold, learning rate, and the initial technology cost, and were based on the “experience curve” concept which describes reductions in production costs as a function of accumulated production volume. As noted above, the typical curve shows a relatively steep initial decline in cost which flattens out to a gentle downwardly sloping line as the volume increase to large values. In the 2008 NPRM, the agencies applied a learning rate discount of 20 percent for each successive doubling of production volume (on a per manufacturer basis), and a learning threshold of 25,000 units was assumed (thus a technology was viewed as being fully learned out at 100,000 units). The factor was only applied to certain technologies that were considered emerging or newly implemented on the basis that significant cost improvements would be achieved as economies of scale were realized (*i.e.*, the technologies were on the steep part of the curve).

In the MY 2011 final rule, the agencies continued to use this learning factor, referring to it as volume-based learning since the cost reductions were determined by production volume increases, and again only applied it to low volume, emerging technologies. However, in response to comments, the agencies revised the assumptions on learning threshold, basing them instead on an industry-wide production basis, and increasing the threshold to 300,000 units annually (thus a technology was considered to be fully learned out at 1.2M annual units).

Additionally, commenters to the 2008 NPRM also described another type of learning factor which NHTSA, working in conjunction with its contractor Ricardo, adopted and implemented for the MY 2011 final rule. Commenters described a relatively small negotiated cost decrease that occurred on an annual basis through contractual agreements with first tier component and systems suppliers. These agreements were generally only applicable to readily available, high volume technologies that were commonly in use by multiple OEMs. Based on the same experience curve principle, however at production volumes that were on the extended, flatter part of the curve (and thus the types of volumes that more accurately represent an annual industry-wide production volume), the agencies adopted this type of learning and referred to it as time-based learning. An annual cost reduction of 3 percent in the second and each subsequent year, which was consistent with estimates from commenters and supported by work that Ricardo conducted for NHTSA, was used in the 2011 final rule.

In response to the 2012-2016 NPRM, NHTSA received comments from ICCT and Ferrari related to learning curves. ICCT stated the agencies could improve the accuracy of the learning curve assumptions if they used a more dynamic or continuous learning curve that is more technology-specific, rather than using step decreases as the current time- and volume-based learning curves appear to do. ICCT also commented on the appropriate application of volume- versus time-based learning, and stated further that worldwide production volumes should be taken into account when developing learning curves. Ferrari commented that it is more difficult for small-volume manufacturers to negotiate cost decreases from things like cost learning effects with their suppliers, implying that learning effects may not be applicable equally for all manufacturers. NHTSA agreed that a continuous curve, if implemented correctly, could potentially improve the accuracy of modeling cost-learning effects. To implement a continuous curve, however, NHTSA would need to develop a learning curve cost model to be integrated into the agency's existing model for CAFE analysis. Due to time constraints in the MY 2012-2016 rulemaking, the agencies were not able to then investigate fully the use of a continuous cost-learning effects curve for each technology, but noted that we would investigate the applicability of this approach for future rulemakings.

Additionally, while NHTSA agreed that worldwide production volumes can impact learning curves, the agency does not forecast worldwide vehicle production volumes in addition to the already complex task of forecasting the U.S. market. That said, the agency does consider current and projected worldwide technology proliferation when determining the maturity of a particular technology used to determine the appropriateness of applying time- or volume-based learning, which helps to account for the effect of globalized production.

With regard to ICCT's comments on the appropriate application of volume- versus time-based learning, however, it seems as though ICCT is referencing a study that defines volume- and time-based learning in a different manner than the current definitions used by NHTSA. NHTSA uses "volume-based" learning for non-mature technologies that have the potential for significant cost reductions through learning, while "time-based" learning is used for mature technologies that have already had significant cost reductions and only have the potential for smaller cost reductions. For "time-based" learning, the agencies chose to emulate the small year-over-year cost reductions manufacturers realize through defined cost reductions, approximately 3 percent per year, negotiated into contracts with suppliers.

And finally, in response to Ferrari's comment, NHTSA recognizes that cost negotiations can be different for different manufacturers, but believes that on balance, cost learning at the supplier level will generally impact costs to all purchasers. Thus, if cost reductions are realized for a particular technology, all entities that purchase the technology will benefit from these cost reductions.

In developing the MY2012-2016 final rule, NHTSA, taking into account comments received, reviewed both types of learning factors, and the thresholds (300,000) and cost reduction rates (20 percent for volume, 3 percent for time-based) they rely on, as implemented in the MY 2011 final rule and the MY2012-2016 NPRM, and concluded that both learning factors continued to be appropriate. NHTSA therefore continued to implement both time- and volume-based learning in the analyses that supported the MY2012-2016 final rule. Noting that only one type of learning can be applied to any single technology, if any learning is applied at all, NHTSA reviewed each technology to determine which if any learning factor was appropriate.

Working under the principle that volume-based learning is applicable to lower volume, higher complexity, emerging technologies while time-based learning is appropriate for high volume, established and readily available technologies, NHTSA established a series of learning schedules which were applied to specific technologies (see Table V-8 in the 2012-2016 FRIA). These factors closely resemble the settings used in the 2011 final rule with the exception of PSHEV which was revised from time-based to volume-based learning. No learning was applied to technologies which are potentially affected by commodity costs (LUB, ROLL) or that have loosely-defined bill of materials (EFR, LDB) in this analysis, as was also the case in the MY 2011 final rule analysis. Where volume-based learning was applied, NHTSA took great care to ensure that the initial costs (before learning is applied) properly reflect low volume, unlearned cost estimates (*i.e.*, any high volume cost estimates used in the analysis have been appropriately "reverse learned" so as not to underestimate the final learned costs).

Regarding these initial volume-based learning costs, ICCT commented that it would be helpful to clarify the assumed production volumes to better interpret the costs of technologies, which are eligible for "volume-based" learning. The agencies did not define the specific cumulative production volume for technologies that are eligible for volume-based learning. When developing the costs for these technologies it was assumed that cumulative production volumes had not exceeded 300,000 but the agencies did not try to specify the exact production volume. Due to the uncertainty of projected production volumes the agency did not believe it appropriate to define costs based on a finer level of detail.

Learning Application in the Current Rulemaking

The learning curves the agency currently uses represent the agency's best estimates regarding the pace of learning. Depending on the technology, the curves assume a learning rate of 3% over the previous years' cost for a number of years, followed by 2% over several more years, followed by 1% indefinitely. In a few cases, larger decreases of 20% are applied every 2 years during the initial years of production before learning decreases to the more typical levels described above. This occurs for the changes that involve relatively new emerging technologies that are not yet mature enough to warrant the slower learning rates.

For this NPRM the agency has, however, adopted new terminology to distinguish the two different learning applications. Emerging technologies are adjusted using what we now call the “steep “learning schedule, which involves the larger 20% decreases, while mature technologies are modified using one of a number of “flat” schedules, involving the smaller 3%, 2%, or 1% decreases. These revised terms reflect the portion of a typical learning curve that would best represent the production history of each technology. Some schedules include both steep and flat characteristics as technologies transition through these phases during the years covered by this analysis. Again, these terms replace the “volume based “ and ”time based” learning terminology that was used in previous CAFE analyses. All learning essentially derives from knowledge gained through accumulated production experience, and the time based terminology seemed to create some confusion among commenters. The modified terminology helps to clarify this point reflects the portion of the volume based learning process that is likely to impact any specific technology.

Table VII-10 lists the various learning schedules that NHTSA applies to technologies for the 2017-2025 PRIA. The schedules are identified by a reference schedule number that was originally assigned to each schedule during the development of the agencies learning methodology. Many other schedules were originally developed, but only those shown in Table VII-10 were considered relevant to the technology costs used in the current analysis. The table illustrates cost reduction rates for years 2010 through 2030. However, only a subset of these years is relevant to each technology, depending on the year in which its direct cost estimate is based and the years in which the technology is applied. The second line in the table indicates the base year that the direct manufacturing costs used by the agencies represent. The learning rates that are indicated prior to the direct manufacturing costs (DMC) base year reflect “prior learning” that was estimated to occur before the base year direct manufacturing cost estimate used by the agencies were developed. So, for example, if a cost estimate for a mature technology reflects expected conditions in MY 2012, there would have already been learning prior to that which would have impacted the MY 2012 costs. Additional learning would then commence in MY 2013.

Table VII-11 lists the technologies that manufacturers may use to achieve higher CAFE levels, and the learning schedule that is applied to each technology. Selection of specific learning curves was based on the agency’s best judgment as to the maturity of each technology and where they would best fit along the learning curve, as well as the year on which their direct manufacturing costs are based.

For example, schedules 11, 12, and 21 are appropriate for technologies that are more mature and have already passed through the steep portion of the learning curve, while schedules 16, 19, 24, and 25 are more appropriate for emerging technologies that will be experiencing learning along the steep part of the curve between MYs 2014-2025.

Table VII-10
Learning Schedules by Model Year Applied to Specific CAFE Technologies

Schedule # =	**6**	**11**	**12**	**16**	**19**	**21**	**24**	**25**
DMC Year =	N/A	2012	2015	2015	2025	2017	2017	2017
Model Year								
2010	0	0.03	0.03	0	0	0.03	0	0
2011	0	0.03	0.03	0	0	0.03	0	0
2012	0	0.03	0.03	0	0	0.03	0	0
2013	0	0.03	0.03	0	0	0.03	0	0
2014	0	0.03	0.03	0.20	0.20	0.03	0.20	0
2015	0	0.03	0.03	0.20	0	0.03	0	0
2016	0	0.03	0.03	0	0.20	0.03	0.20	0
2017	0	0.02	0.02	0.03	0	0.03	0	0
2018	0	0.02	0.02	0.03	0.20	0.03	0.03	0
2019	0	0.02	0.02	0.03	0	0.03	0.03	0.20
2020	0	0.02	0.02	0.03	0.20	0.03	0.03	0
2021	0	0.02	0.02	0.03	0	0.03	0.03	0.2
2022	0	0.02	0.02	0.03	0	0.03	0.03	0.03
2023	0	0.02	0.02	0.03	0	0.02	0.03	0.03
2024	0	0.02	0.02	0.03	0	0.02	0.03	0.03
2025	0	0.02	0.02	0.03	0.20	0.02	0.03	0.03
2026	0	0.01	0.01	0.02	0.03	0.02	0.02	0.03
2027	0	0.01	0.01	0.02	0.03	0.02	0.02	0.02
2028	0	0.01	0.01	0.02	0.03	0.01	0.02	0.02
2029	0	0.01	0.01	0.02	0.03	0.01	0.02	0.02
2030	0	0.01	0.01	0.02	0.03	0.01	0.02	0.02

Table VII-11
Learning Schedules for Specific CAFE Technologies

Technology	**Learning Schedule**
Low Friction Lubricants - Level 1	6
Engine Friction Reduction - Level 1	6
Low Friction Lubricants and Engine Friction Reduction - Level 2	6
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	12
Discrete Variable Valve Lift (DVVL) on SOHC	12
Cylinder Deactivation on SOHC	11
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	12
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	12
Discrete Variable Valve Lift (DVVL) on DOHC	12
Continuously Variable Valve Lift (CVVL)	12
Cylinder Deactivation on DOHC	11
Stoichiometric Gasoline Direct Injection (GDI)	11

Cylinder Deactivation on OHV	12
Variable Valve Actuation - CCP and DVVL on OHV	12
Stoichiometric Gasoline Direct Injection (GDI) on OHV	11
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement – Turbo	11
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement - Downsize	11
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement –Turbo	11
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement - Downsize	11
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement – Turbo	11
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement - Downsize	11
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement - Turbo	11
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement - Downsize	11
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement - Turbo	11
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement - Downsize	11
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement - Turbo	11
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement - Downsize	11
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement - Turbo	11
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement – Downsize	11
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement - Turbo	11
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement – Downsize	11
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement – Turbo	11
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement – Downsize	11
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement – Turbo	11
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement – Downsize	11
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement – Turbo	11
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement – Downsize	11
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement – Turbo	11
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement – Downsize	11
Advanced Diesel - Small Displacement	11
Advanced Diesel - Medium Displacement	11
Advanced Diesel - Large Displacement	11
6-Speed Manual/Improved Internals	12
Improved Auto. Trans. Controls/Externals	12
6-Speed Trans with Improved Internals (Auto)	11
6-speed DCT	11
8-Speed Trans (Auto or DCT)	11
High Efficiency Gearbox w/ dry sump (Auto or DCT)	21
Shift Optimizer	21
Electric Power Steering	12
Improved Accessories - Level 1	12

Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	12
12V Micro-Hybrid (Stop-Start)	16
Integrated Starter Generator	16
Strong Hybrid (Powersplit or 2-Mode) - Level 1 – Battery	24
Strong Hybrid (Powersplit or 2-Mode) - Level 1 - Non-Battery	11
Conversion from SHEV1 to SHEV2	N/A
Strong Hybrid (P2 Parallel or 2-Mode) - Level 2 – Battery	24
Strong Hybrid (P2 Parallel or 2-Mode) - Level 2 - Non-Battery	11
Plug-in Hybrid - 20 mi range – Battery	19
Plug-in Hybrid - 20 mi range - Non-Battery	11
Plug-in Hybrid - 40 mi range – Battery	19
Plug-in Hybrid - 40 mi range - Non-Battery	11
Electric Vehicle (Early Adopter) - 75 mile range – Battery	19
Electric Vehicle (Early Adopter) - 75 mile range - Non-Battery	21
Electric Vehicle (Early Adopter) - 100 mile range – Battery	19
Electric Vehicle (Early Adopter) - 100 mile range - Non-Battery	21
Electric Vehicle (Early Adopter) - 150 mile range – Battery	19
Electric Vehicle (Early Adopter) - 150 mile range - Non-Battery	21
Electric Vehicle (Broad Market) - 150 mile range – Battery	19
Electric Vehicle (Broad Market) - 150 mile range - Non-Battery	21
Fuel Cell Vehicle	???
Charger-PHEV20	19
Charger-PHEV40	19
Charger-EV	19
Charger Labor	6
Mass Reduction - Level 1	21
Mass Reduction - Level 2	21
Mass Reduction - Level 3	21
Mass Reduction - Level 4	21
Mass Reduction - Level 5	21
Low Rolling Resistance Tires - Level 1	6
Low Rolling Resistance Tires - Level 2	25
Low Rolling Resistance Tires - Level 3	N/A
Low Drag Brakes	6
Secondary Axle Disconnect	12
Aero Drag Reduction, Level 1	12
Aero Drag Reduction, Level 2	12

Application of a Continuous Learning Curve to CAFE Technologies

The purpose of the schedules employed by NHTSA is to approximate a learning curve. An alternate approach would be to apply a learning curve directly to the current cost estimates. As noted above, in response to comments received during previous rulemakings, NHTSA agreed that a continuous curve, if implemented correctly, could potentially improve the accuracy of modeling cost-learning effects, and noted that we would investigate the applicability of this approach for future rulemakings. Following are the results of this analysis.

The basis for a continuous learning curve has been established in the literature. The method commonly mentioned in the literature estimates learning as a function of cumulative production.

Essentially, each doubling of cumulative production results in a specified percentage reduction in costs. The specified reduction percentage is a function of the "progress rate". The progress rate represents the portion of costs that remain after each step of learning. The progress rate usually cited is 0.8, implying that each doubling of cumulative production results in a 20% reduction in costs[255].

According to Dutton and Thomas[256], the most common formulation of the progress function is the log-linear form:

Where:
y=input cost for the xth unit
x= cumulative number of units produced
a=input cost for the first unit
b= progress rate

Figure VII-2 portrays an example of cost decreases that occur over successive doublings of cumulative production under an assumed learning rate. The increments indicated on the x axis of Figure VII-2 represent successive instances of doubling of cumulative volume. The rate of cost decline is initially steep, but flattens out naturally over subsequent production increases. Doubling during the earlier years of a technologies life can occur relatively quickly once production is initiated in large portions of the fleet. Thus, for example, a single year's production could produce 3 or 4 instances of doubling. However, as cumulative volume grows, the rate of doubling decreases since annual increases in cumulative production are limited to one year's production level, while cumulative volume increases indefinitely. Successive doublings may require ever increasing multiples of years to occur.

Figure VII-3 illustrates the practical impact of cumulative learning over time using a hypothetical production schedule for a new technology. The increments indicated on the x axis of Figure VII-3 represent successive years in a technologies production life. In this example, successive doublings of cumulative production occur in the first few years as production is ramped up over the initial levels that occurred as the technology was introduced into the fleet, possibly in luxury or specialty vehicles. However, within a few years cumulative volume exceeds the stabilized annual production volume, and doubling becomes increasingly difficult to obtain. Both Figure VII-2 and Figure VII-3 are based on the same learning rate, but Figure VII-3 reflects the natural limitation on increases in cumulative volume (and thus learning) that result from the finite nature of annual production levels.

Figure VII-2 also illustrates a practical limitation to the application of learning curves. If followed to its natural conclusion, the indefinite application of learning curves, even at relatively low rates, implies that technology costs will eventually approach zero, an infeasible result for virtually all automotive technologies. This in turn implies that there is likely some point at which learning will basically be exhausted and will cease to have an observable impact on costs – a threshold at which further application of learning would no longer be appropriate. Very few

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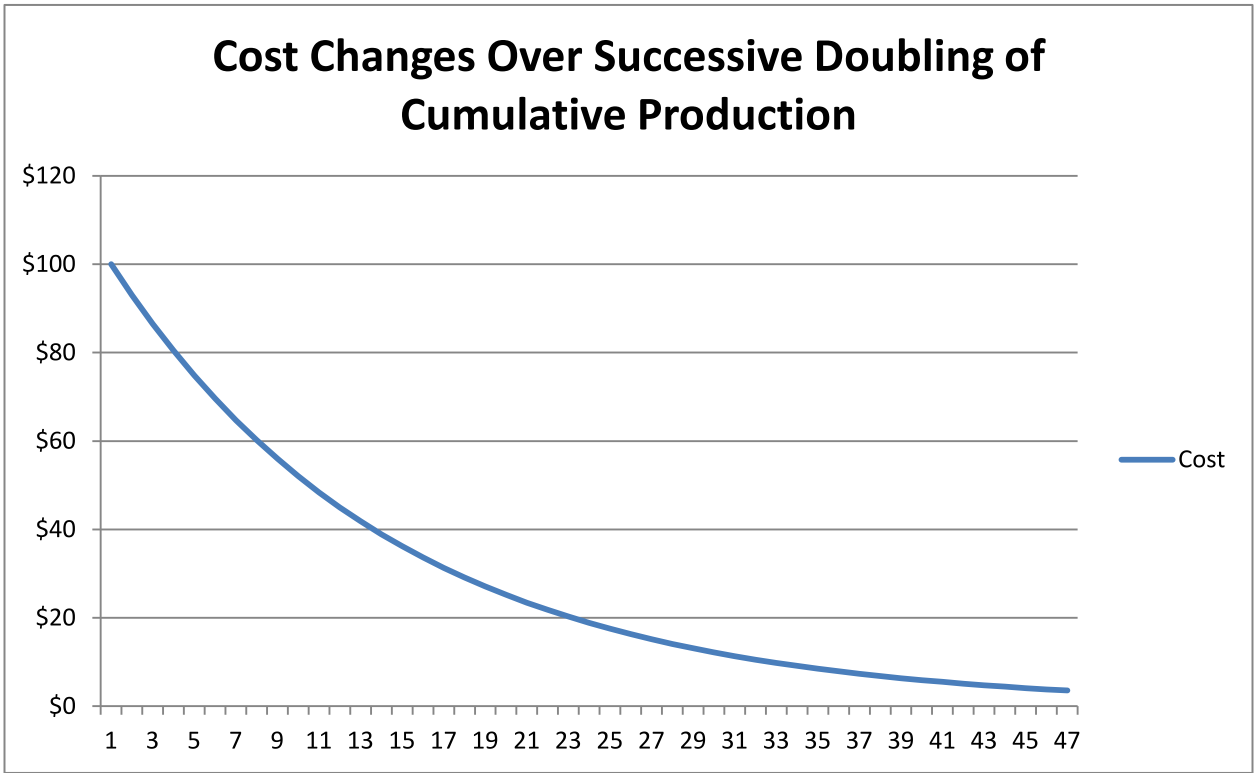
[255] Dutton, John M, and Thomas, Annie, "Treating Progress Functions as a Managerial Opportunity", Academy of Management Review, 1984, Vol. 9, No. 2, pp.235-247

[256] Ibid

of the technologies used to improve CAFE are expected to last for more than 20 years, so practically speaking, the application of learning within the context of CAFE analyses is unlikely to produce such a result. While some breakthrough technologies have experienced significant cost reductions to levels that are a fraction of their original cost, it is likely that for most motor vehicle technologies, real reductions in cost began to be less feasible as they drop beyond a certain level. Baloff[257] examined automotive assembly labor costs for 4 different start-up scenarios during the late 1960s and found that in 3 of the 4 scenarios, assembly costs reached a steady state condition where no further learning occurred when cumulative output reached 40 percent of the total annual production. Assembly labor is only one aspect of total production costs – production techniques can be refined, material prices can change as cheaper sources are found, etc., but it seems likely that a practical floor exists for most if not all aspects of production. The National Research Council of the National Academy of Sciences warns against applying traditional learning curves to mature technologies for this same reason.[258]

Neither the cumulative production method, nor the proxy learning schedules currently used by NHTSA and EPA recognize a steady state cost level, but as can be seen in Figure VII-3, they do eventually reach a point where costs decline at such a slow rate that the impact of further production is relatively insignificant. The agencies do not currently have data to determine whether the timing of real world steady state cost trends is consistent with the trends that result from our learning curve estimates.

FIGURE VII-2



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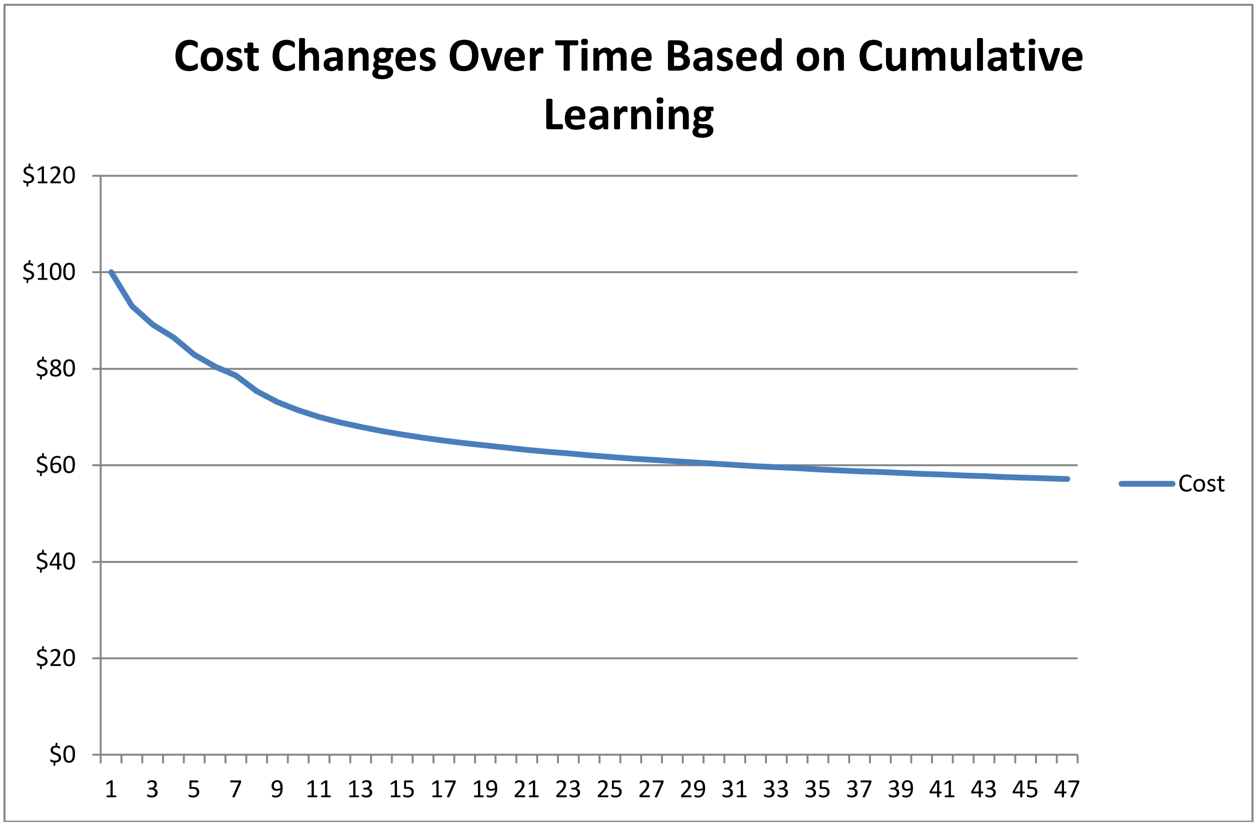
[257] Baloff, Nicholas, Extension of the Learning Curve – Some Empirical Results, Operational Research Quarterly (1970-0971), Vol 22, No. 4 (Dec., 1971, pp.32-43.

[258] National Research Council of the National Academies, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, *Assessment for Fuel Economy Technologies for Light-Duty Vehicles*, Washington D.C.: The National Academies Press, June 2011, p. 25. Available at http://www.nap.edu/catalog.php?record_id=12924 or Docket No. NHTSA-2010-0131

FIGURE VII-3



As noted in the previous discussion, over the past several rulemakings NHTSA has attempted to simulate the learning process using a variety of methods and assumptions. NHTSA has not directly employed a cumulative volume algorithm for this purpose because to do so would require specific assumptions regarding the appropriate progress ratio for each technology, as well as information regarding the cumulative volume of each technology concurrent with its cost basis. The progress rate most often cited in the literature, 80%, is a general average derived from Dutton and Thomas' 1984 compilation of over 100 empirical studies of progress curves in a large variety of industries between 1920 and 1980[259]. However, as those authors are careful to point out, the average progress rate across all of these studies has not been found to be a good predictor for specific industries. Baloff too warns against use of this simple average, referring to it as "the infamous "80 percent" curve"[260].

Table VII-12 summarizes the progress rates, along with the implied cost reduction rates for a variety of technologies gathered from more recent studies. For these technologies, a range of progress rates are indicated, averaging closer to 90% than 80%. However, none of these technologies are produced within the light vehicle industry or in volumes similar to those produced in that industry (although PV inverters require electronics technology similar to that used in some automotive applications).

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[259] Dutton op.cit.
[260] Baloff op. cit, p.41

Table VII-12
Progress Rates and Learning Rates for Selected Technologies

Technology	Progress Rate	Learning Rate
Solar Power[261]	0.77	0.23
Wind Power[262]	0.87	0.13
Ethanol[263]	0.85	0.15
PV Inverters[264]	0.94	0.06
Solar Thermal[265]	0.97	0.03
Flue Gas DeSOx[266]	0.89	0.11
Flue Gas DeNOx[267]	0.88	0.12

To properly estimate the impact of learning under the cumulative volume approach, five things are required:

1) A progress rate representing the remaining portion of the price after each doubling of cumulative volume
2) The direct cost of the technology at time n1
3) An estimate of the cumulative production volume for the specific technology at time n1
4) The direct cost of the technology at time n2
5) A history of the production of the technology between time n1 and n2

In an effort to explore the potential impacts of adopting a cumulative production curve (rather than simulating one with proxy estimates contained in schedules), NHTSA has examined the cost and production changes for several light vehicle technologies. NHTSA routinely performs evaluations of the costs and benefits of safety standards that were previously promulgated. To estimate costs, the agency conducts a tear down study of the technologies used to meet the standards. In some cases, the agency has performed multiple evaluations over a span of years. For example, a tear down study may be performed to support the agency's initial estimates of costs that will result from the regulation, and again 5 years later to evaluate the impacts of the regulation after it has been in effect. These data, together with actual production data, supply 4 of the 5 items required to develop a learning curve for the technology. Combining them with the methods previously discussed, we were able to derive a progress rate specific to each technology.

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[261] The Carbon Productivity Challenge: Curbing Climate Change and Sustaining Economic Growth, McKinsey Climate Change Special Initiative, McKinsey Global Institute, June 2008 (quoting from UC Berkeley Energy Resource Group, Navigant Consulting). Available at: http://www.mckinsey.com/mgi/reports/pdfs/Carbon_Productivity/MGI_carbon_productivity_full_report.pdf or Docket No. NHTSA-2010-0131

[262] Ibid

[263] Ibid

[264] Ibid

[265] Ibid

[266] Technology Innovation for Climate Mitigation and its Relation to Government Policies, Edward S. Rubin, Carnegie Mellon University, Presentation to the UNFCCC Workshop on Climate Change Mitigation, Bonn, Germany, June 19, 2004. Available at http://www.cmu.edu/epp/iecm/rubin/PDF%20files/2004/2004th%20Rubin,%20National%20Coal%20Council%20May%20(c).pdf or Docket No. NHTSA-2010-0131

[267] Ibid

The technologies that were examined were air bags, antilock braking systems, 3-point manual outboard safety belts with retractors, dual master brake cylinders, and adjustable head restraints. The derived progress rates for each technology are summarized in Table VII-13:

Table VII-13

Progress Rates and Learning Rates for Automotive Safety Technologies

Technology	Progress Rate	Learning Rate
Driver Air Bags	0.93	0.07
Antilock Braking Systems	0.90	0.10
Manual Lap/Shoulder Belts	0.96	0.04
Adjustable Head Restraints	0.91	0.09
Dual Master Brake Cylinders	0.95	0.05

The results range from 0.90 for antilock brakes to 0.96 for 3-point belts with retractors. The average progress rate for these 5 technologies is 0.93. This limited sample of these safety related automotive technologies thus indicates a progress rate for technologies used in passenger vehicles that is roughly .10-.15 higher than the all-industry average noted in Dutton and Thomas and others.

NHTSA does not have similar data for the specific technologies that will be used to meet CAFE standards. Specifically, we do not have cost teardown information over at least 2 time periods for these technologies, and in most cases we do not have the cumulative production volume associated with the cost estimates that are used in the Volpe model. However, we were able to determine the cumulative volume production for two specific technologies - turbochargers (TRBDS) and electronic power steering (EPS). These data were gathered from Ward's Automotive Reports annuals, which specify production levels for some selected technologies, and from AA1CAR.com. In cases where data was not yet available though the year of the cost estimate, a conservative estimate based on the most recent years production or projections derived from the Volpe model was added to the total to represent the few missing years. We thus had a current cost estimate and the cumulative production that was concurrent with that cost estimate. In addition, we had our own projections for future production of these technologies through 2025, and our own calculated price for that technology through 2025 reflecting our current learning schedules. Using these data, we estimated the implied progress ratio that was consistent with the learning schedules we apply in our models that would produce the same cost estimate in MY 2025 as is predicted in our models. The resulting progress rates were 0.92 for turbochargers and .90 for electronic power steering. We note that, unlike the 5 safety technologies discussed above, these are not actual measurements of the learning curve progress rate for these technologies, rather they are measurements of the implied progress rate that results from the learning schedules we are applying. The implication is that we are applying learning schedules for these two technologies that would be consistent with progress rates of roughly 0.92 and 0.90[268]. These are somewhat lower than, but reasonably consistent with, the average measured progress rates for the 5 safety technologies.

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[268] Note that these progress rates were derived based on the curve that matched the Volpe model predicted costs in MY 2025. They were not necessarily best fit curves over the entire time span. Based on an examination of the curves in figures 3 and 4, we believe a best fit curve would produce a nearly identical progress ratio for the turbo, and would produce a slightly higher progress rate for electronic power steering.

As a final step in this analysis, NHTSA ran a comparison of the price trends that result from application of the current learning schedules to the trends that would result from applying the cumulative learning procedure assuming the average progress ratio of 0.93 derived from the 5 vehicle safety technologies. The results are illustrated in Figures VII-4 and VII-5 below. In each case the technologies were assigned a token cost of $100 to facilitate examination of the results. In the case of turbos, the cumulative production method produces cost estimates that range from near zero in the early years to about 4% more than the current learning schedule over by MY2025. In the case of electronic power steering, the cumulative production method produces cost estimates that exceed the current learning schedule by near zero in the early years but that steadily rise to 7% by MY 2025.

This analysis indicates that the learning schedules used in the NPRM for these technologies provides cost estimates that are within 4-7% of cost estimates derived using a cumulative production basis, with smaller differences in earlier years. However, a number of caveats are required. The most obvious is that it is not certain that the average progress rate derived from the 5 safety technologies is actually representative of the progress rate that should be applicable to the roughly 40 different fuel economy technologies that will be incorporated into vehicle designs for CAFE. Although the range of progress rates for these safety technologies, 90-96%, is relatively narrow, if real data were available to measure the progress rate for all 40 CAFE technologies, it is likely that the range may be wider. It is uncertain how this would directionally affect the average.

FIGURE VII-4
TRBDS Cost Trend Under Current Learning Schedule and Cumulative Learning Basis

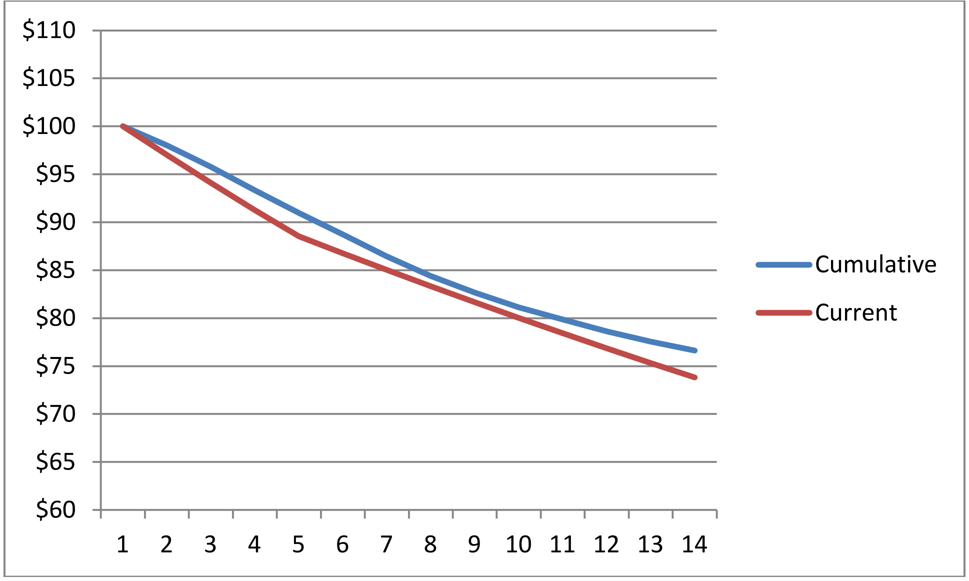
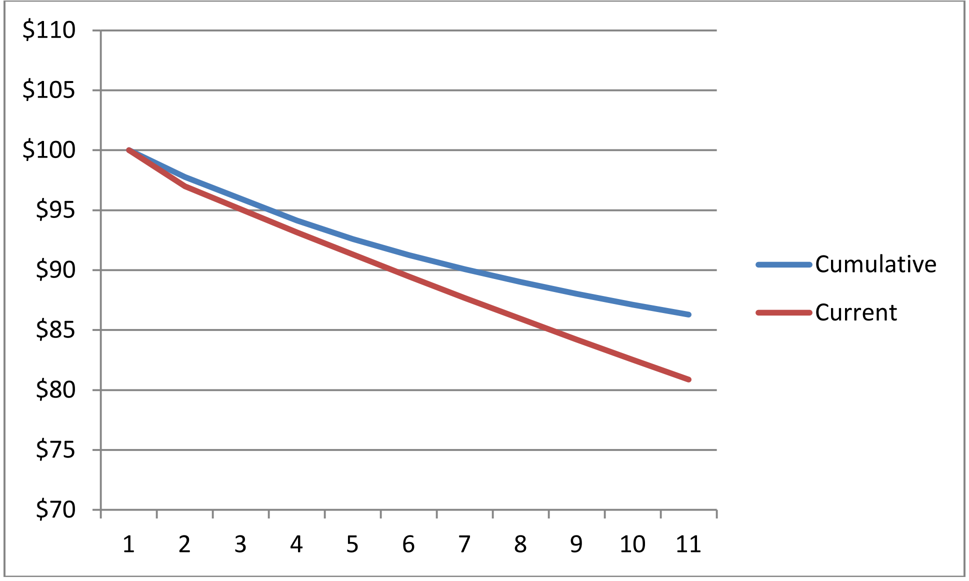


FIGURE VII-5
EPS Cost Trend Under Current Learning Schedule and Cumulative Learning Basis



A second caveat is that calculations of derived progress rates are highly sensitive to estimates of cumulative production. Empirical observations from this exercise indicate that each doubling or halving of the assumed initial cumulative production can shift calculated progress rates by 0.01-0.02 or more, depending on the historical sales profile. It is thus important that initial cost estimates properly match up with the correct assessment of the cumulative production volumes that coincide with those costs, and for most technologies, this data is elusive. Although the cumulative production method has theoretical advantages over using a series of learning schedules based on expert judgment, as a practical matter, an inability to obtain this data could lead to the adoption of assumed or roughly estimated levels of cumulative production. This might result in replacing one set of judgments with another, and it is unclear which would have the greater margin of error.

We note that the cost estimates provided in the FEV report represent the cost to annually produce mature technologies in a volume of 450,000 units. Mature technologies as defined in that study have mature product designs, high production volumes, significant marketplace competition, and established manufacturing processes. Presumably, in order for a technology to be considered mature it would have already been produced for a number of years so that production and assembly techniques had been refined to a level of efficiency where it could be considered a mature technology. For each of the 2 technologies examined above, cumulative production volume through 2009 was over 4 million units, but these technologies are projected to grow at noticeably different rates in response to CAFE standards after 2009. It is likely that cumulative production for the 40+ technologies estimated in this study will have a wide range of cumulative volumes for MY 2012 (the base year for most technologies in the FEV report) , which could make application of a single assumed cumulative volume level problematic.

In summary, to actually adopt a cumulative production based learning methodology that is confidently more accurate than current methods, NHTSA would have to develop at least 2 historical cost estimates for each technology, a cumulative production volume estimate coinciding with the initial cost estimate, and a schedule of cumulative production between the cost estimates. With these data we could derive an accurate progress rate to apply to each technology going forward using the projected increase in cumulative production volume that is predicted to result from CAFE standards. This initial analysis of only two CAFE technologies and five safety technologies indicates that adopting a cumulative production basis for learning applications could produce cost estimates that are within 4-7% of those used in the NPRM by 2025, with less variation in earlier years. However, this analysis is based on a very small sample of technologies and the data required to more precisely evaluate this issue are currently unavailable. Further, these data may not be obtainable without an extensive research effort, if at all.

Overall, NHTSA acknowledges that there is uncertainty regarding the rate of learning that will occur for specific CAFE technologies. The schedules that are applied in this analysis represent our best effort to approximate the learning history that would typically occur over the course of a technology's lifetime, with the our best judgment as to the position of each technology along the learning curve. The agency requests comments regarding the learning rates currently used in this analysis, the application of cumulative learning curves to technologies, and any data sources that might assist in developing learning rates for specific CAFE technologies.

Potential opportunity costs of improved fuel economy

An important concern is whether achieving the fuel economy improvements required by alternative CAFE standards would require manufacturers to compromise the performance, carrying capacity, safety, or comfort of their vehicles. If it did so, the resulting sacrifice in the value of these attributes to vehicle buyers would represent an additional cost of achieving the required improvements in fuel economy, and thus of manufacturers' compliance with stricter CAFE standards. While exact dollar values of these attributes to buyers are extremely difficult to infer from vehicle purchase prices, it is nevertheless clear that changes in these attributes can affect the utility that vehicles provide to their owners, and thus their value to potential buyers.

The agency has approached this potential problem by developing cost estimates for fuel economy-improving technologies that include any additional manufacturing costs that would be necessary to maintain the performance, comfort, capacity, or safety of any vehicle to which those technologies are applied. Theoretically, opportunity costs could also include any foregone opportunities to enhance these products for consumers. However, estimating values for foregone opportunities is an even tougher task. So, the agency followed the precedent established by the National Academy of Sciences (NAS) in its 2002 analysis of the costs and benefits of improving fuel economy by raising CAFE standards.[269] The NAS study estimated "constant performance

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[269] National Academy of Sciences, ***Costs and Effectiveness of Increasing Corporate Average Fuel Economy Standards***, 2002.

and utility" costs for fuel economy technologies, and the agency has used these as the basis for developing the technology costs it employed in analyzing manufacturer's costs for complying with alternative standards.

NHTSA fully acknowledges the difficulty of estimating technology costs that include costs for the accompanying changes in vehicle design that are necessary to maintain performance, capacity, and utility. This is particularly difficult for electric vehicles and the potential effect that reduced driving distance could have on buying patterns and sales. This will be discussed further in Chapter VIII in the section on "The Value to Consumers of Changes in Driving Range."

Financial Impacts of Raising CAFE Standards

Market forces are already requiring manufacturers to improve the fuel economy of their vehicles, as shown both by changes in product plans reported to NHTSA, and by automaker public announcements. The various compliance flexibility mechanisms permitted by EISA, including flexible and alternative fuel vehicles, banking, averaging, and trading of fuel economy credits will also reduce compliance costs to some degree. By statute, NHTSA is not permitted to consider the benefits of flexibility mechanisms in setting fuel economy standards.

President Obama announced plans for these proposed rules on July 29, 2011 and NHTSA and EPA issued a Supplemental Notice of Intent (NOI) outlining the agencies' plans for proposing the MY 2017-2025 standards and program.[270]

This proposal reflects an agreement between EPA, NHTSA, CARB, 13 automobile companies, and general support from the United Auto Workers on desirable and achievable fuel economy standards. We believe that this agreement reflects the view of the industry that given current economic conditions that the standards finalized here are economically practicable. On the other hand, the agency is mindful that CAFE standards could affect the relative competitiveness of different vehicle manufacturers.

Given the foregoing, therefore, the agency has decided that in this exceptional situation, economic practicability must be determined based on whether the expenditures needed to achieve compliance with the MY 2017-2025 standards are "within the financial capability of the industry, but not so stringent as to threaten substantial economic hardship for the industry."

One of the primary ways in which the agency seeks to ensure that its standards are within the financial capability of the industry is to attempt to ensure that manufacturers have sufficient lead time to modify their manufacturing plans to comply with the final standards in the model years covered by them. Employing appropriate assumptions about lead time in our analysis helps to avoid applying technologies before they are ready to be applied, or when their benefits are insufficient to justify their costs. It also helps avoid basing standards on the assumption that

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[270] 76 FR 48758 (August 9, 2011).

technologies could be applied more rapidly than practically achievable by manufacturers. NHTSA considers these matters in its analysis of issues including refresh and redesign schedules, phase-in caps, and learning rates.

The agency has neither the capability to predict the capital investment needs of the automobile industry to install fuel economy technologies, nor the capability to determine the level of capital investments available to specific manufacturers in the future.

Sales and Employment

Projected Sales of MY 2017-2025 Passenger Cars and Light Trucks

Projections of total passenger car and light truck sales for future years were obtained using the Annual Energy Outlook 2011 (AEO 2011) version of Energy Information Administration's (EIA's), National Energy Modeling System (NEMS), as described in the agencies' joint Technical Support Document (TSD) supporting today's proposed rule. AEO is a standard government reference for projections of energy production and consumption in different sectors of the U.S. economy. In using these forecasts, NHTSA made the simplifying assumption that the NEMS-based projected sales of cars and light trucks during each calendar year from 2017 through 2025 represented the likely production volumes for the corresponding model year. The agency did not attempt to establish the exact correspondence between projected sales during individual calendar years and production volumes for specific model years, instead the analysis is done on a model year basis.

As also discussed in the TSD, NHTSA and EPA jointly made use of a custom long-range forecast purchased from CSM Worldwide. This forecast addressed trends such as changes in individual manufacturers' shares of the U.S. light vehicle market and changes in the prominence of different market segments (*e.g.*, crossover vehicles).

The final market forecast applied by NHTSA reflects growth of the overall fleet to match the NEMS-based forecast of the overall size of the fleet, as well as normalization of the production volumes of individual vehicle models in consideration of (a) NEMS-based estimates of the sizes of the passenger car and light truck fleets, (b) CSM-based estimates of individual manufacturers' market shares, and (c) CSM-based estimates of the prominence of specific market segments. These adjustments were conducted through an iterative process also described in the TSD, and result in the production (for the U.S. market) volumes shown below:

Table VII-14a
Sales Projections – Passenger Cars

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Industry	9987667	9905364	9995696	10291562	10505165
Aston Martin	1035	1051	1072	1034	1058
BMW	313022	322939	346075	357942	359098
Daimler	284847	276409	281425	290989	300378
Fiat	425439	404238	398483	422235	428072
Ford	1299899	1311467	1332039	1378789	1401617
Geely	88234	89394	91575	93003	92726
General Motors	1462204	1474076	1493511	1544983	1564277
Honda	1154600	1138087	1144639	1163666	1198880
Hyundai	592027	578373	582971	598283	613355
Kia	322044	312370	314879	323676	331319
Lotus	240	243	250	266	278
Mazda	253540	262512	266951	270078	274740
Mitsubishi	65099	63671	63826	65080	65851
Nissan	870797	849678	854400	882791	912629
Porsche	35093	35444	36116	35963	36475
Spyker	20024	20007	20144	21069	21294
Subaru	224112	216598	217095	223466	230780
Suzuki	90708	89932	90568	93548	95725
Tata	55881	56222	57267	58182	58677
Tesla	27986	28435	28990	27965	28623
Toyota	1849196	1834181	1836306	1883734	1903706
Volkswagen	551638	540036	537114	554822	585607

Table VII-14a
Sales Projections – Passenger Cars
Continued

	MY 2022	MY 2023	MY 2024	MY 2025
Industry	10735777	10968003	11258138	11541560
Aston Martin	1049	1041	1141	1182
BMW	360034	360561	388193	405256
Daimler	304738	312507	332337	340719
Fiat	431311	431110	433458	444137
Ford	1415221	1474797	1503670	1540109
Geely	92512	96840	99181	101107
General Motors	1578556	1606495	1636805	1673936
Honda	1237504	1265564	1307851	1340321
Hyundai	627964	634308	657710	677250
Kia	339102	342746	351882	362783
Lotus	290	299	308	316
Mazda	281150	296910	300614	306804
Mitsubishi	67261	67680	70728	73305
Nissan	937447	954340	982771	1014775
Porsche	36607	36993	39504	40696
Spyker	21709	22410	22800	23130
Subaru	238613	241612	248283	256970
Suzuki	97599	99263	100447	103154
Tata	59349	60639	63728	65418
Tesla	28369	28150	30862	31974
Toyota	1986077	2036992	2080528	2108053
Volkswagen	593314	596749	605336	630163

Table VII-14b
Sales Projections – Light Trucks

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Industry	5818655	5671046	5582962	5604377	5683902
Aston Martin	0	0	0	0	0
BMW	138053	131942	131373	128339	128724
Daimler	86913	83651	88188	92919	99449
Fiat	409702	387858	366447	360677	348613
Ford	763549	748829	717773	717037	714181
Geely	41887	42187	43125	42615	41768
General Motors	1362761	1438355	1505025	1530755	1530020
Honda	596481	544619	527535	525089	535916
Hyundai	152885	151461	155642	154173	156466
Kia	98702	98280	100679	96535	95432
Lotus	0	0	0	0	0
Mazda	51788	57535	57494	58154	59227
Mitsubishi	37632	36300	35454	35215	35309
Nissan	444938	412383	398559	397869	408029
Porsche	13233	12001	11469	11141	11242
Spyker	2871	3596	3826	3509	3560
Subaru	78242	75152	72832	72458	72773
Suzuki	22109	21385	20692	20675	20767
Tata	57579	56606	57854	56213	58153
Tesla	0	0	0	0	0
Toyota	1330511	1223415	1142104	1154304	1215539
Volkswagen	128819	145491	146891	146700	148734

Table VII-14b
Sales Projections – Light Trucks
Continued

	MY 2022	MY 2023	MY 2024	MY 2025
Industry	5703996	5687486	5675949	5708899
Aston Martin	0	0	0	0
BMW	128899	127521	146525	145409
Daimler	100935	105315	107084	101067
Fiat	363008	361064	344962	331762
Ford	714266	700005	688854	684476
Geely	41686	42031	42461	42588
General Motors	1507653	1496819	1493597	1524008
Honda	539235	536898	536994	557697
Hyundai	157493	161189	166092	168136
Kia	94694	95688	96119	97653
Lotus	0	0	0	0
Mazda	60307	61966	61971	61368
Mitsubishi	35227	35469	36001	36387
Nissan	411883	417121	422217	426454
Porsche	11385	11370	11409	11219
Spyker	3461	3435	3426	3475
Subaru	72736	73022	74142	74722
Suzuki	20734	20803	21162	21374
Tata	58590	58865	57981	56805
Tesla	0	0	0	0
Toyota	1235052	1224980	1208013	1210016
Volkswagen	146750	153927	156939	154284

The Impact of Higher Prices on Sales and Employment

In past fuel economy analyses, the agency has made estimates of sales impacts comparing increases in vehicle price to the savings in fuel over a 5 year period. We chose 5 years because this is the average length of time of a financing agreement.[271] As discussed below, for this analysis we have conducted a fresh search of the literature for additional estimates of consumer valuation of fuel savings, in order to determine whether the 5 year assumption was accurate or whether it should be revised. That search has led us to the conclusion for this proposed rule that consumer valuation of future fuel savings is highly uncertain. A negative impact on sales is certainly possible, because the proposed rule will lead to an increase in the initial price of vehicles. A positive impact is also possible, because the proposed rule will lead to a significant decrease in the lifetime cost of vehicles, and with consumer learning over time, this effect may produce an increase in sales. In light of the relevant uncertainties, the agency therefore decided not to include a quantitative sales estimate and requests comments on all of the discussion here, including the question whether a quantitative estimate (or range) is possible.

The effect of this rule on sales of new vehicles depends largely on how potential buyers evaluate and respond to its effects on vehicle prices and fuel economy. The rule will make new cars and light trucks more expensive, as manufacturers attempt to recover their costs for complying with the rule by raising vehicle prices. At the same time, the rule will require manufacturers to improve the fuel economy of many of their models, which will lower their operating costs. The initial cost of vehicles will increase but the overall cost will decrease. The net effect on sales will depend on the extent to which consumers are willing to pay for fuel economy.

The earlier discussion of consumer welfare suggests that by itself, a net decrease in overall cost may not produce a net increase in sales, because many consumers are more affected by upfront cost than by overall cost, and will not be willing to purchase vehicles with greater fuel economy even when it appears to be in their economic interest to do so (assuming standard discount rates). But there is considerable uncertainty in the economics literature about the extent to which consumers value fuel savings from increased fuel economy, and there is still more uncertainty about possible changes in consumer behavior over time (especially with the likelihood of consumer learning). The effect of this proposed regulation on vehicle sales will depend upon whether the overall value that potential buyers place on the increased fuel economy is greater or less than the increase in vehicle prices and how automakers factor that into price setting for the various models.

Two economic concepts bear on how consumers might value fuel savings. The first relates to the length of time that consumers consider when valuing fuel savings and the second relates to the discount rate that consumers apply to future savings. These two concepts are used together to determine consumer valuation of future fuel savings. The length of time that consumers

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[271] National average financing terms for automobile loans are available from the Board of Governors of the Federal Reserve System G.19 "Consumer Finance" release. *See* http://www.federalreserve.gov/releases/g19/ (last accessed August 25, 2011). The average new car loan at an auto finance company in the first quarter of 2011 is for 62 months at 4.73 %.

consider when valuing future fuel savings can significantly affect their decision when they compare their estimates of fuel savings with the increased cost of purchasing higher fuel economy. There is a significant difference in fuel savings if you consider the savings over 1 year, 3 years, 5 years, 10 years, or the lifetime of the vehicle. The discount rate that consumers use to discount future fuel savings to present value can also have a significant impact. If consumers value fuel savings over a short period, such as 1 to 2 years, then the discount rate is less important. If consumers value fuel savings over a long period, then the discount rate is important.

The length of time consumers consider when valuing fuel savings

Information regarding the number of years that consumers value fuel savings (or undervalue fuel savings) come from several sources. In past analyses NHTSA has used five years as representing the average new vehicle loan. A recent paper by David Greene[272] examined studies from the past 20 years of consumers' willingness to pay for fuel economy and found that "the available literature does not provide a reasonable consensus." In his paper Greene states that "manufacturers have repeatedly stated that consumers will pay, in increased vehicle price, for only 2 - 4 years in fuel savings." These estimates were derived from manufacturer's own market research. And the National Research Council[273] used a 3 year payback period as one of its ways to compare benefits to a full lifetime discounting. A survey conducted for the Department of Energy in 2004,[274] which asked 1,000 households how much they would pay for a vehicle that saved them $400 or $1,200 per year in fuel costs, found implied payback periods of 1.5 to 2.5 years In reviewing this survey, Greene concluded: "The striking similarity of the implied payback periods from the two subsamples would seem to suggest that consumers understand the questions and are giving consistent and reliable responses: they require payback in 1.5 to 2.5 years."

However, Turrentine and Kurani's[275] in-depth interviews of 57 households found almost no evidence that consumers think about fuel economy in terms of payback periods. When asked such questions, some consumers became confused while others offered time periods that were meaningful to them for other reasons, such as the length of their car loan or lease.

The discount rate that consumers apply to future fuel savings

The effective discount rate that consumers have used in the past to value future fuel economy savings has been studied in many different ways and by many different economists. Greene[276] examined and compiled many of these analyses and found: "Implicit consumer discount rates

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[272] "Why the Market for New Passenger Cars Generally Undervalues Fuel Economy", David Greene, Oak Ridge National Laboratory, 2010, Pg. 17, http://www.internationaltransportforum.org/jtrc/DiscussionPapers/DP201006.pdf

[273] National Research Council (2002) "Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards", National Academies Press, Washington D.C.

[274] Opinion Research Corporation (2004), "CARAVAN" ORC study #7132218, for the National Renewable Energy Laboratory Princeton, New Jersey, May 20, 2004.

[275] Turrentine, T.S. and K.S. Kurani, 2007. "Car Buyers and Fuel Economy," *Energy Policy*, vol. 35, pp. 1213-1223.

[276] "Why the Market for New Passenger Cars Generally Undervalues Fuel Economy", David Greene, Oak Ridge National Laboratory, 2010.

were estimated by Greene (1983) based on eight early mutinomial logit choice models. …The estimates range from 0 to 73% ... Most fall between 4 and 40%." Greene added: "The more recent studies exhibit as least a wide a range as the earlier studies."

With such uncertainty about how consumers value future fuel savings and the discount rates they might use to determine the present value of future fuel savings, NHTSA would utilize the standard 3 and 7 percent discount rates. It is true that some consumers appear to show higher discount rates, which would affect the analysis of likely sales consequences; NHTSA invites comments on the nature and extent of that effect.

In past analyses, NHTSA assumed that consumers would consider the fuel savings they would obtain over the first five years of vehicle ownership, which is consistent with the average loan rates and the average length of first vehicle ownership. The five-year span is somewhat longer than the period found to be used by consumers in some studies, but use of a shorter period may also reflect a lack of salience or related factors, and as noted, use of the five-year span has the advantage of tracking the average length of first vehicle ownership. NHTSA continues to use the five-year period here. As with discount rates, NHTSA invites comments on this issue and in particular on the possible use of a shorter period.

It is true that the payback period and discount rate are conceptual proxies for consumer decisions that may often be made without any corresponding explicit quantitative analysis. For example, some buyers choosing among some set of vehicles may know what they have been paying recently for gasoline, may know what they are likely to pay to buy each of the vehicles consider, and may know some of the attributes—including labeled fuel economies—of those vehicles. Such buyers may then make a choice without actually trying to estimate how much they would pay to fuel each of the vehicles they are considering buying. In other words, for such buyers, the idea of a payback period and discount rate may have no explicit meaning. This does not, however, limit the utility of these concepts for the agency's analysis. If, as a group, buyers behave *as if* they value fuel consumption considering a payback period and discount rate, these concepts remain useful as a basis for estimating the market response to increases in fuel economy accompanied by increases in price.

NHTSA's previous analytical approach updated

There is a broad consensus in the economic literature that the price elasticity for demand for automobiles is approximately –1.0.[277, 278, 279] Thus, every one percent increase in the price of the vehicle would reduce sales by one percent. Elasticity estimates assume no perceived change in the quality of the product. However, in this case, vehicle price increases result from adding

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[277] Kleit, A.N. (1990). "The Effect of Annual Changes in Automobile Fuel Economy Standards," *Journal of Regulatory Economics*, vol. 2, pp 151-172. Available at http://www.rff.org/documents/RFF-DP-03-44.pdf (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131

[278] Bordley, R. (1994). "An Overlapping Choice Set Model of Automotive Price Elasticities," *Transportation Research B*, vol 28B, no 6, pp 401-408. Available at http://www.sciencedirect.com/science/article/B6V99-466M3VD-1/2/3ecfe61bac45f1afb8d9b370330e3f0c (last accessed November 14, 2011)

[279] McCarthy, P.S. (1996). "Market Price and Income Elasticities of New Vehicle Demands," *The Review of Economics and Statistics*, vol. LXXVII, no. 3, pp. 543-547. Available at http://econpapers.repec.org/article/tprrestat/v_3a78_3ay_3a1996_3ai_3a3_3ap_3a543-47.htm (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131

technologies that improve fuel economy. This elasticity is generally considered to be a short-run elasticity, reflecting the immediate impacts of a price change on vehicle sales.

For a durable good such as an auto, the elasticity may be smaller in the long run: though people may be able to change the timing of their purchase when price changes in the short run, they must eventually make the investment. Using a smaller elasticity would reduce the magnitude of the estimates presented here for vehicle sales, but it would not change the direction. A short-run elasticity is more valid for initial responses to changes in price, but, over time, a long-run elasticity may better reflect behavior; thus, the results presented for the initial years of the program may be more appropriate for modeling with the short-run elasticity than the later years of the program. A search of the literature has not found studies more recent than the 1970s that specifically investigate long-run elasticities.[280]

One approach to determine the breakeven point between vehicle prices and fuel savings is to look at the payback periods shown earlier in this analysis. For example at a 3 percent discount rate, the payback period for MY 2025 vehicles is 2 years for light trucks and 4 years for passenger cars.

In determining the payback period we make several assumptions. For example, we follow along with the calculations that are used for a 5 year payback period, as we have used in previous analyses. For the fuel savings part of the equation, we assumed as a starting point that the average purchaser considers the fuel savings they would receive over a 5 year timeframe. The present values of these savings were calculated using a 3 and 7 percent discount rate. We used a fuel price forecast (see Table VIII-3) that included taxes, because this is what consumers must pay. Fuel savings were calculated over the first 5 years and discounted back to a present value.

The agency believes that consumers may consider several other factors over the 5 year horizon when contemplating the purchase of a new vehicle. The agency added these factors into the calculation to represent how an increase in technology costs might affect consumers' buying considerations.

First, consumers might consider the sales taxes they have to pay at the time of purchasing the vehicle. We took sales taxes in 2010 by state and weighted them by population by state to determine a national weighted-average sales tax of 5.5 percent.[281]

Second, we considered insurance costs over the 5 year period. More expensive vehicles will require more expensive collision and comprehensive (*e.g.*, theft) car insurance. The increase in insurance costs is estimated from the average value of collision plus comprehensive insurance as a proportion of average new vehicle price. Collision plus comprehensive insurance is the portion

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[280] E.g., Hymans, Saul H. "Consumer Durable Spending: Explanation and Prediction." Brookings Papers on Economic Activity 1 (1970): pp.173-206 finds a short-run elasticity of auto expenditures (not sales) with respect to price of 0.78 to 1.17, and a long-run elasticity of 0.3 to 0.46. Available at: http://www.brookings.edu/~/media/Files/Programs/ES/BPEA/1970_2_bpea_papers/1970b_bpea_hymans_ackley_juster.pdf or Docket No. NHTSA-2010-0131

[281] Based on data found in http://www.api.org/statistics/fueltaxes/ (last accessed November 14, 2011)

of insurance costs that depend on vehicle value. The Insurance Information Institute[282] provides the average value of collision plus comprehensive insurance in 2006 as $448, which is $480 in 2009$. The average consumer expenditure for a new passenger car in 2010, according to the Bureau of Economic Analysis was $24,092 and the average price of a new light truck $30,641 in $2009.[283] Using sales volumes from the Bureau, we determined an average passenger car and an average light truck price was $27,394 in $2009 dollars. Average prices and estimated sales volumes are needed because price elasticity is an estimate of how a percent increase in price affects the percent decrease in sales.

Dividing the insurance cost by the average price of a new vehicle gives the proportion of comprehensive plus collision insurance as 1.75% of the price of a vehicle. If we assume that this premium is proportional to the new vehicle price, it represents about 1.75 percent of the new vehicle price and insurance is paid each year for the five year period we are considering for payback. Discounting that stream of insurance costs back to present value indicates that the present value of the component of insurance costs that vary with vehicle price is equal to 8.0 percent of the vehicle's price at a 3 percent discount rate.

Third, we considered that 70 percent of new vehicle purchasers take out loans to finance their purchase. The average new vehicle loan in the first quarter of 2011 is 5.3 percent.[284] At these terms the average person taking a loan will pay 14 percent more for their vehicle over the 5 years than a consumer paying cash for the vehicle at the time of purchase.[285] Discounting the additional 2.8 percent (14 percent / 5 years) per year over the 5 years using a 3 percent mid-year discount rate[286] results in a discounted present value of 12.73 percent higher for those taking a loan. Multiplying that by the 70 percent that take a loan, means that the average consumer would pay 8.9 percent more than the retail price for loans the consumer discounted at a 3 percent discount rate.

Fourth, we considered the residual value (or resale value) of the vehicle after 5 years and expressed this as a percentage of the new vehicle price. If the price of the vehicle increases due to fuel economy technologies, the resale value of the vehicle will go up proportionately. The average resale price of a vehicle after 5 years is about 35%[287] of the original purchase price. Discounting the residual value back 5 years using a 3 percent discount rate (35 percent * .8755) gives an effective residual value of 30.6 percent. Note that added CAFE technology could also

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[282] Insurance Information Institute, 2008, "Average Expenditures for Auto Insurance by State, 2005-2006," *available at* http://www.iii.org/media/facts/statsbyissue/auto/ (last accessed March 4, 2010).

[283] 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/SelectTable.asp#S7 (last accessed November 14, 2011)

[284] New car loan rates in the first quarter of 2011 averaged 5.86 percent at commercial banks and 4.73 percent at auto finance companies, so their average is close to 5.3 percent.

[285] Based on www.bankrate.com auto loan calculator for a 5 year loan at 5.3 percent.

[286] For a 3 percent discount rate, the summation of 2.8 percent x 0.9853 in year one, 2.8 x 0.9566 in year two, 2.8 x 0.9288 in year three, 2.8 x 0.9017 in year 4, and 2.8 x 0.8755 in year five.

[287] Consumer Reports, August 2008, "What That Car Really Costs to Own," Available at http://www.consumerreports.org/cro/cars/pricing/what-that-car-really-costs-to-own-4-08/overview/what-that-car-really-costs-to-own-ov.htm (last accessed March 4, 2010).

result in more expensive or more frequent repairs. However, we do not have data to verify the extent to which this would be a factor during the first 5 years of vehicle life.

We add these four factors together. At a 3 percent discount rate, the consumer considers he could get 30.6 percent back upon resale in 5 years, but will pay 5.5 percent more for taxes, 8.1 percent more in insurance, and 8.9 percent more for loans, results in a 8.1 percent return on the increase in price for fuel economy technology (30.6 percent – 5.5 percent - 8.1 percent – 8.9 percent). Thus, the increase in price per vehicle would be multiplied by 0.919 (1 – 0.081) before subtracting the fuel savings to determine the overall net consumer valuation of the increase of costs on this purchase decision. This process results in estimates of the payback period for MY 2025 vehicles of 2 years for light trucks and 4 years for passenger cars at a 3 percent discount rate.

<u>A general discussion of consumer considerations</u>
If consumers do not value improved fuel economy at all, and consider nothing but the increase in price in their purchase decisions, then the estimated impact on sales from price elasticity could be applied directly. However, the agency anticipates that consumers will place some value improved fuel economy, because they reduce the operating cost of the vehicles, and because, based on recently-promulgated EPA and DOT regulations, vehicles sold during through 2025 will display labels that more clearly communicate to buyers the fuel savings, economic, and environmental benefits of more efficient vehicles. The magnitude of this effect remains unclear, and how much consumers value fuel economy is an ongoing debate. We know that different consumers value different aspects of their vehicle purchase,[288] but we do not have reliable evidence of consumer behavior on this issue. Several past consumer surveys lead to different conclusions (and surveys themselves, as opposed to actual behavior, may not be entirely informative). We also expect that consumers will consider other factors that affect their costs, and have included these in the analysis.

One issue that significantly affects this sales analysis is: How much of the retail price increase needed to cover the fuel economy technology investments will manufacturers be able to pass on to consumers? NHTSA typically assumes that manufacturers will be able to pass all of their costs to improve fuel economy on to consumers. Consumer valuation of fuel economy improvements often depends upon the price of gasoline, which has recently been very volatile.

Sales losses would occur only if consumers fail to value fuel economy improvements at least as much as they pay in higher prices. If manufacturers are unable to raise prices beyond the level of consumer's valuation of fuel savings, then manufacturer's profit levels would fall but there would be no impact on sales. Likewise, if fuel prices rise beyond levels used in this analysis, consumer's valuation of improved fuel economy could increase to match or exceed their initial investment, resulting in no impact or even an increase in sales levels.

The agency has been exploring the question why there is not more consumer demand for higher fuel economy today when linked with our methodology that results in projecting increasing sales

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[288] For some consumers there will be a cash-flow problem in that the vehicle is purchased at a higher price on day 1 and fuel savings occur over the lifetime of the vehicle. Increases in prices have sometimes led to longer loan periods, which would lead to higher overall costs of the loan.

for the future when consumers are faced with rising vehicle prices and rising fuel economy. Some of the discussion of salience, focus on the short-term, loss aversion, and related factors (see above) bears directly on that question. It is possible, in that light, that consumers will not demand increased fuel economy even when such increases would produce net benefits for them.

Nonetheless, some current vehicle owners, including those who currently drive gas guzzlers, will undoubtedly realize the net benefits to be gained by purchasing a more efficient vehicle. Some vehicle owners may also react to persistently higher vehicle costs by owning fewer vehicles, and keeping existing vehicles in service for somewhat longer. For these consumers, the possibility exists that there may be permanent sales losses, compared with a situation in which vehicle prices are lower.

There is a wide variety in the number of miles that owners drive per year. Some drivers only drive 5,000 miles per year and others drive 25,000 miles or more. Rationally those that drive many miles have more incentive to buy vehicles with high fuel economy levels

In summary, there are a variety of types of consumers that are in different financial situations and drive different mileages per year. Since consumers are different and use different reasoning in purchasing vehicles, and we do not yet have an account of the distribution of their preferences or how that may change over time as a result of this rulemaking --- in other words, the answer is quite ambiguous. Some may be induced by better fuel economy to purchase vehicles more often to keep up with technology, some may purchase no new vehicles because of the increase in vehicle price, and some may purchase fewer vehicles and hold onto their vehicles longer. There is great uncertainty about how consumers value fuel economy, and for this reason, the impact of this fuel economy proposal on sales is uncertain.

For years, consumers have been learning about the benefits that accrue to them from owning and operating vehicles with greater fuel efficiency. Consumer demand has thus shifted towards such vehicles, not only because of higher fuel prices but also because many consumers are learning about the value of purchases based not only on initial costs but also on the total cost of owning and operating a vehicle over its lifetime. This type of learning is expected to continue before and during the model years affected by this rule, particularly given the new fuel economy labels that clarify potential economic effects and should therefore reinforce that learning. Therefore, some increase in the demand for, and production of, more fuel efficient vehicles is incorporated in the [alternative] baseline (i.e., without these rules) [developed by NHTSA]. The agency requests comment on the appropriateness of using a flat or rising baseline after 2016.

Today's proposed rule, combined with the new and easier-to-understand fuel economy label required to be on all new vehicles beginning in 2012, may increase sales above baseline levels by hastening this very type of consumer learning. As more consumers experience, as a result of the rule, the savings in time and expense from owning more fuel efficient vehicles, demand may shift yet further in the direction of the vehicles mandated under the rule. This social learning can take place both within and across households, as consumers learn from one another.

First and most directly, the time and fuel savings associated with operating more fuel efficient vehicles will be more salient to individuals who own them, causing their subsequent purchase decisions to shift closer to minimizing the total cost of ownership over the lifetime of the vehicle. Second, this appreciation may spread across households through word of mouth and other forms of communications. Third, as more motorists experience the time and fuel savings associated with greater fuel efficiency, the price of used cars will better reflect such efficiency, further reducing the cost of owning more efficient vehicles for the buyers of new vehicles (since the resale price will increase).

If these induced learning effects are strong, the rule could potentially increase total vehicle sales over time. These increased sales would not occur in the model years first affected by the rule, but they could occur once the induced learning takes place. It is not possible to quantify these learning effects years in advance and that effect may be speeded or slowed by other factors that enter into a consumer's valuation of fuel efficiency in selecting vehicles.

The possibility that the rule will (after a lag for consumer learning) increase sales need not rest on the assumption that automobile manufacturers are failing to pursue profitable opportunities to supply the vehicles that consumers demand. In the absence of the rule, no individual automobile manufacturer would find it profitable to move toward the more efficient vehicles mandated under the rule. In particular, no individual company can fully internalize the future boost to demand resulting from the rule. If one company were to make more efficient vehicles, counting on consumer learning to enhance demand in the future, that company would capture only a fraction of the extra sales so generated, because the learning at issue is not specific to any one company's fleet. Many of the extra sales would accrue to that company's competitors.

In the language of economics, consumer learning about the benefits of fuel efficient vehicles involves positive externalities (spillovers) from one company to the others[289]. These positive externalities may lead to benefits for manufacturers as a whole.

We emphasize that this discussion has been tentative and qualified. To be sure, social learning of related kinds has been identified in a number of contexts[290]. Comments are invited on the discussion offered here, with particular reference to any relevant empirical findings."

How does NHTSA plan to address this issue for the final rule?

NHTSA seeks comment on how to attempt to quantify sales impacts of the proposed MYs 2017-2025 CAFE standards in light of the uncertainty discussed above. The agency is currently sponsoring work to develop a vehicle choice model for potential use in the agency's future rulemaking analysis—this work may help to better estimate the market's effective valuation of future fuel economy improvements. The agency hopes to evaluate those potential impacts

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[289] Industry-wide positive spillovers of this type are hardly unique to this situation. In many industries, companies form trade associations to promote industry-wide public goods. For example, merchants in a given locale may band together to promote tourism in that locale. Antitrust law recognizes that this type of coordination can increase output.

[290] See Hunt Alcott, Social Norms and Energy Conservation, Journal of Public Economics (forthcoming 2011), available at http://web.mit.edu/allcott/www/Allcott%202011%20JPubEc%20-%20Social%20Norms%20and%20Energy%20Conservation.pdf; Christophe Chamley, Rational Herds: Economic Models of Social Learning (Cambridge, 2003).

through use of a “market shift” or “consumer vehicle choice” model, discussed in Section IV of the NPRM preamble. With an integrated market share model, the CAFE model would then estimate how the sales volumes of individual vehicle models would change in response to changes in fuel economy levels and prices throughout the light vehicle market, possibly taking into account interactions with the used vehicle market. Having done so, the model would replace the sales estimates in the original market forecast with those reflecting these model-estimated shifts, repeating the entire modeling cycle until converging on a stable solution. We seek comment on the potential for this approach to help the agency estimate sales effects for the final rule.

Others studies of the sales effect of this CAFE proposal

We outline here other relevant studies and seek comment on their assumptions and projections.

A recent study on the effects on sales, attributed to regulatory programs, including the fuel economy program was undertaken by the Center for Automotive Research (CAR)[291]. CAR examined the impacts of alternative fuel economy increases of 3%, 4%, 5%, and 6% per year on the general outlook for the U.S. motor vehicle market, the likely increase in costs for fuel economy (based on the NAS report, which estimates higher costs than NHTSA’s current estimates) and required safety features, the technologies used and how they would affect the market, production, and automotive manufacturing employment in the year 2025. The required safety mandates were assumed to cost $1,500 per vehicle in 2025, but CAR did not value the safety benefits from those standards. NHTSA does not believe that the assumed safety mandates should be a part of this analysis without estimating the benefits achieved by the safety mandates.

There are many factors that go into the CAR analysis of sales. CAR assumes a 22.0 mpg baseline, two gasoline price scenarios of $3.50 and $6.00 per gallon, VMT schedules by age, and a rebound rate of 10 percent (although it appears that the CAR report assumes a rebound effect even for the baseline and thus negates the impact of the rebound effect). Fuel savings are assumed to be valued by consumers over a 5 year period at a 10 percent discount rate. The impact on sales varies by scenario, the estimates of the cost of technology, the price of gasoline, etc. At $3.50 per gallon, the net change in consumer savings (costs minus the fuel savings valued by consumers) is a net cost to consumers of $359 for the 3% scenario, a net cost of $1,644 for the 4% scenario, a net cost of $2,858 for the 5% scenario, and a net consumer cost of $6,525 for the 6% scenario. At $6.00 per gallon, the net change in consumer savings (costs minus the fuel savings valued by consumers) is a net savings to consumers of $2,107 for the 3% scenario, a net savings of $1,131 for the 4% scenario, a net savings of $258 for the 5% scenario, and a net consumer cost of $3,051 for the 6% scenario. Thus, the price of gasoline can be a significant factor in affecting how consumers view whether they are getting value for their expenditures on technology.

Table 14 on page 42 of the CAR report presents the results of their estimates of the 4 alternative mpg scenarios and the 2 prices of gasoline on light vehicle sales and automotive employment. The table below shows these estimates. The baseline for the CAR report is 17.9 million sales

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[291] “The U.S. Automotive Market and Industry in 2025”, Center for Automotive Research, June 2011. http://www.cargroup.org/pdfs/ami.pdf

and 877,075 employees. The price of gasoline at $6.00 per gallon, rather than $3.50 per gallon results in about 2.1 million additional sales per year and 100,000 more employees in year 2025.

CAR report estimates of sales and employment impacts
Impacts in 2025

Gasoline at $3.50	CAFE requirement of a 3% increase in mpg per year	CAFE requirement of a 4% increase in mpg per year	CAFE requirement of a 5% increase in mpg per year	CAFE requirement of a 6% increase in mpg per year
Sales (millions)	16.4	15.5	14.7	12.5
Employment	803,548	757,700	717,626	612,567
Gasoline at $6.00				
Sales	18.5	17.6	16.9	14.5
Employment	903,135	861,739	826,950	711,538

Figure 13 on page 44 of the CAR report shows a graph of historical automotive labor productivity, indicating that there has been a long term 0.4 percent productivity growth rate from 1960-2008, to indicate that there will be 12.26 vehicles produced in the U.S. per worker in 2025 (which is higher than NHTSA's estimate – see below). In addition, the CAR report discusses the jobs multiplier. For every one automotive manufacturing job, they estimate the economic contribution to the U.S. economy of 7.96 jobs[292] stating "In 2010, about 1 million direct U.S. jobs were located at an auto and auto parts manufacturers; these jobs generated an additional 1.966 million supplier jobs, largely in non-manufacturing sectors of the economy. The combined total of 2.966 jobs generated a further spin-off of 3.466 million jobs that depend on the consumer spending of direct and supplier employees, for a total jobs contribution from U.S. auto manufacturing of 6.432 million jobs in 2010. The figure actually rises to 7.96 million when direct jobs located at new vehicle dealerships (connected to the sale and service of new vehicles) are considered."

CAR uses econometric estimates of the sensitivity of new vehicle purchases to prices and consumer incomes and forecasts of income growth through 2025 to translate these estimated changes in net vehicle prices to estimates of changes in sales of MY 2025 vehicles; higher net prices – which occur when increases in vehicle prices exceeds the value of fuel savings – reduce vehicle sales, while lower net prices increase new vehicle sales in 2025. We do not have access to the statistical models that CAR develops to estimate the effects of price and income changes on vehicle sales. CAR's analysis assumes continued increases in labor productivity over time and then translates the estimated impacts of higher CAFE standards on net vehicle prices into estimated impacts on sales and employment in the automobile production and related industries. The agency disagrees with the cost estimates in the CAR report for new technologies, the addition of safety mandates into the costs, and various other assumptions.

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[292] Kim Hill, Debbie Menk, and Adam Cooper, "Contribution of the Automotive Industry to the Economies of All Fifty States and the United States", The Center for Automotive Research, Ann Arbor MI, April 2010.

An analysis conducted by Ceres and Citigroup Global Markets Inc.[293] examined the impact on automotive sales in 2020, with a baseline assumption of an industry fuel economy standard of 42 mpg, a $4.00 price of gasoline, a 12.2 percent discount rate and an assumption that buyers value 48% of fuel savings over seven years in purchasing vehicles. The main finding on sales was that light vehicle sales were predicted to increase by 6% from 16.3 million to 17.3 million in 2020. Elasticity is not provided in the report but it states that they use a complex model of price elasticity and cross elasticities developed by GM. A fuel price risk factor[294] was utilized. Little rationale was provided for the baseline assumptions, but sensitivity analyses were examined around the price of fuel ($2, $4, and $7 per gallon), the discount rate (5.2%, 12.2%, 17.2%), purchasers consider fuel savings over (3, 7, or 15 years), fuel price risk factor of (30%, 70%, or 140%), and VMT of (10,000, 15,000, and 20,000 in the first year and declining thereafter).

Potential Impact on Employment

There are three potential areas of employment that fuel economy standards could affect[295]. We briefly outline those areas here and invite comment on the appropriate analysis.

1. The first is the hiring of additional engineers by automobile companies and their suppliers to do research and development and testing on new technologies to determine their capabilities, durability, platform introduction, etc. The agency anticipates that there will be some level of additional job creation due to the added research and development, overall program management, and subsequent sales efforts required to market vehicles that have been redesigned for significant improvements in fuel economy, especially for revolutionary technologies such as hybrid and electric vehicles. In this respect, the proposed rule will likely have a positive effect on employment. At the same time, the levels of added employment are uncertain. In addition, it is not clear how much of this effort will be accomplished by added employment and how much by diverting existing employees to focus on CAFE instead of other company priorities such as improved performance, styling, marketing, new vehicle concepts, etc.

2. The second area is the impact that new technologies would have on the production line. Added parts or complexity of assembly could have a positive impact on employment. The use of more exotic steels, aluminum, or other materials to save weight could affect the number of welds or attachment methods. Again, it is uncertain to what extent new CAFE technologies would require added steps in the assembly process that would necessitate new hiring.

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[293] "U.S. Autos, CAFE and GHG Emissions", March 2011, Citi Ceres, UMTRI, Baum and Associates, Meszler Engineering Services, and the Natural Resources Defense Council.
http://www.ceres.org/resources/reports/fuel-economy-focus

[294] Fuel price risk factor measures the rate at which consumers are willing to trade reductions in fuel costs for increases in purchase price. For example, a fuel price risk factor of 1.0 would indicate the consumers would be willing to pay $1 for an improvement in fuel economy that resulted in reducing by $1 the present value of the savings in fuel costs.

[295] For a general analysis of the potentially complex employment effects of regulation, see Morgenstern, Richard D., William A. Pizer, and Jhih-Shyang Shih. "Jobs Versus the Environment: An Industry-Level Perspective." Journal of Environmental Economics and Management 43 (2002): 412-436 (Docket EPA-HQ-OAR-2010-0799).

3. The third area is the potential impact that sales gains or losses could have on production employment. This area is potentially much more sensitive to change than the first two areas discussed above, although for reasons discussed above its estimation is highly uncertain. An increase in sales, produced for example by consumer attention to overall costs and learning over time, would have a positive effect on employment. A decrease in sales, produced by increases in initial costs, would have a negative effect.

In order to obtain an estimate of potential job losses per sales loss, we examined recent U.S. employment (original equipment manufacturers and suppliers) and U.S. production. Total employment in 2000 reached a peak in the Motor Vehicle and Parts Manufacturing sector of the economy averaging 1,313,500 workers (NAICS codes of 3361, 2, 3). Since then there has been a steady decline to 1,096,900 in 2006 and more rapid decreases in 2008, and 2009. Employment in 2009 averaged 664,000, employment in 2010 averaged 675,000 and employment in the first six months of 2011 has averaged 699,000. Table VII-15 shows how many vehicles are produced by the average worker in the industry. Averaging the information shown for the even years of 2000-2010, the average U.S. domestic employee produces 11.3 vehicles (the same number as in 2008 and 2010). Thus, one could assume that a projected sales gain or loss divided by 11.3 would give an estimate of the potential employment gain or loss.

We also examined the employment impact for production and non-supervisory workers from the Bureau of Labor Statistics to see if there was a more direct link between their employment level and production than the white collar workers. There is a closer link between light vehicle production in the U.S. and the number of production and non-supervisory workers (for example, from 2002 to 2010, production fell by 44 percent; the number of production and non-supervisory workers in the industry fell by 44 percent and the number of white collar workers fell by 31 percent). However, in some years (2004 and 2006) the white-collar jobs had a higher percentage loss than the blue-collar jobs. We decided it was more important to examine all jobs in the industry, and not determine the effect on employment based on only the production and non-supervisory workers.

Table VII-15
U.S. Light Duty Vehicle Production and Employment

	U.S. Light Vehicle Production	Motor Vehicle and Parts U.S. Employment[296]	Production per Employee
2000	12,773,714	1,313,500	9.7
2002	13,568,385	1,151,300	11.8
2004	13,527,309	1,112,700	12.2

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[296] U.S. employment data is from the Bureau of Labor Statistics, *available at* http://data.bls.gov/PDQ/servlet/SurveyOutputServlet?series_id=CES3133600101&data_tool=XGtable (last accessed March 4, 2010).

2006	12,855,845	1,069,800	11.7
2008	9,870,473	875,400	11.3
2010	7,597,147	674,600	11.3
Total/Average	70,192,873	6,197,300	11.3

When the economy is at full employment, a fuel economy regulation is unlikely to have much impact on net overall U.S. employment; instead, labor would primarily be shifted from one sector to another. These shifts in employment impose an opportunity cost on society, approximated by the wages of the employees, as regulation diverts workers from other activities in the economy. In this situation, any effects on net employment are likely to be transitory as workers change jobs (e.g., some workers may need to be retrained or require time to search for new jobs, while shortages in some sectors or regions could bid up wages to attract workers). On the other hand, if a regulation comes into effect during a period of high unemployment, a change in labor demand due to regulation may affect net overall U.S. employment because the labor market is not in equilibrium[297].

Schmalansee and Stavins point out that net positive employment effects are possible in the near term when the economy is at less than full employment due to the potential hiring of idle labor resources by the regulated sector to meet new requirements (e.g., to install new equipment) and new economic activity in sectors related to the regulated sector.[298] In the longer run, the net effect on employment is more difficult to predict and will depend on the way in which the related industries respond to the regulatory requirements.

This program is expected to affect employment in the regulated sector (auto manufacturing) and other sectors directly affected by the proposal: auto parts suppliers, auto dealers, the fuel supply market (which will face reduced petroleum production due to reduced fuel demand but which may see additional demand for electricity or other fuels). As discussed in the CAR report above, each of these sectors could potentially have ripple effects throughout the rest of the economy. These ripple effects depend much more heavily on the state of the economy than do the direct effects. As noted above, though, in a full-employment economy, any changes in employment will result from people changing jobs or voluntarily entering or exiting the workforce. In a full-employment economy, employment impacts of this proposal will change employment in specific sectors, but it will have small, if any, effect on aggregate employment. This rule would take effect in 2017 through 2025; by then, the current high unemployment may be moderated or ended. For that reason, this analysis does not include multiplier effects, but instead focuses on employment impacts in the most directly affected industries. Those sectors are likely to face the most concentrated employment impacts.

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[297] Posner and Masur, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=192044

[298] Schmalensee, Richard, and Robert N. Stavins. "A Guide to Economic and Policy Analysis of EPA's Transport Rule." White paper commissioned by Excelon Corporation, March 2011.

Since the impact of this proposal on sales is unknown, and sales have the largest potential effect on employment, the impact of this proposal on employment is also unknown. We invite public comment on the underlying questions.

Scrappage Rates

The effect of this rule on the use and scrappage of older vehicles will be related to its effects on new vehicle prices, the fuel efficiency of new vehicle models, and the total sales of new vehicles. If the value of fuel savings resulting from improved fuel efficiency to the typical potential buyer of a new vehicle outweighs the average increase in new models' prices, sales of new vehicles will rise, while scrappage rates of used vehicles will increase slightly. This will cause the "turnover" of the vehicle fleet – that is, the retirement of used vehicles and their replacement by new models – to accelerate slightly, thus accentuating the anticipated effect of the rule on fleet-wide fuel consumption and CO_2 emissions. However, if potential buyers value future fuel savings resulting from the increased fuel efficiency of new models at less than the increase in their average selling price, sales of new vehicles will decline, as will the rate at which used vehicles are retired from service. This effect will slow the replacement of used vehicles by new models, and thus partly offset the anticipated effects of the final rules on fuel use and emissions.

Because the agencies are uncertain about how the value of projected fuel savings from the final rules to potential buyers will compare to their estimates of increases in new vehicle prices, we have not attempted to estimate explicitly the effects of the rule on scrappage of older vehicles and the turnover of the vehicle fleet.

VIII. BENEFITS FROM IMPROVED FUEL ECONOMY

A. Accounting for the Fuel Economy Rebound Effect

The rebound effect refers to the increase in vehicle use that results if an increase in fuel efficiency lowers the cost per mile of driving, which can encourage people to drive slightly more. Because this additional driving consumes some fuel and increases emissions, it reduces fuel savings and increases emissions compared to those otherwise expected from the proposed standards. Thus the magnitude of the rebound effect is one of the determinants of the actual fuel savings and emission reductions that are likely to result from adopting stricter fuel economy or emissions standards, and is thus an important parameter affecting EPA's and NHTSA's evaluation of the proposed and alternative standards for future model years.

The rebound effect is measured directly by estimating the change in vehicle use, often expressed in terms of vehicle miles traveled (VMT), with respect to changes in vehicle fuel efficiency.[299] However, it is a common practice in the literature to measure the rebound effect by estimating the change in vehicle use with respect to the fuel cost per mile driven, which depends on both vehicle fuel efficiency and fuel prices.[300] When expressed as a positive percentage, these two parameters give the ratio of the percentage increase in vehicle use that results from a percentage increase in fuel efficiency or reduction in fuel cost per mile, respectively. For example, a 10 percent rebound effect means that a 10 percent decrease in fuel cost per mile is expected to result in a 1 percent increase in VMT.

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.[301] 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.[302]

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[299] 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.

[300] 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.

[301] 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.

[302] 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.

The following sections survey these previous studies and summarize recent work on the rebound effect,[303] and explain the basis for the 10 percent rebound effect EPA and NHTSA are using in this proposed rulemaking.

Summary of Historical Literature on the 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 proposal will affect future driving behavior. Therefore, the more recent studies are described in more detail further 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 Table VIII-1.

Table VIII-1

Estimates of the Rebound Effect Using U.S. Aggregate Time-Series Data on Vehicle Travel[304]

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

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[303] 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.

[304] *Ibid.*

Table VIII-2

Estimates of the Rebound Effect Using U.S. State Level Data[305]

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 (at sample average) 1966-2001 (at 1997-2001 avg.)
Hymel, Small and Van Dender (2010)	4.7% 4.8%	24.1% 15.9%	1966-2004 1984-2004

While studies using national (Table VIII-1) and state level (Table VIII-2) data have found relatively consistent long-run estimates of the rebound effect, household surveys display more variability (Table VIII-3). There are several possible explanations for this larger variability. One explanation is that some of these studies do not include vehicle age as an explanatory variable, thus leading to omitted variable bias in some of their estimates.[306] Another 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 with higher fuel prices are more likely to reside in urban areas.[307]

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[305] Source: Sorrell and Dimitropolous (2007) and the agencies' addition of recent work by Small and Van Dender (2007a) and Hymel, Small, and Van Dender (2010).

[306] Greening, Lorna A., David L. Greene, and Carmen Difiglio, "Energy Efficiency and Consumption – the Rebound Effect – A Survey" Lorna A. Greening, David L. Greene, Carmen Difiglio. Energy Policy (28) 2000, pp. 389-401.

[307] 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.

Table VIII-3

Estimates of the Rebound Effect Using U.S. Survey Data[308]

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

It is important to note that some of these studies actually quantify the price elasticity of gasoline demand (*e.g.*, Puller & Greening[309]) 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 the fuel cost per mile of driving. The latter of these measures more closely matches the definition of the fuel economy rebound effect. In fact, none of the studies cited above estimate the direct measure of the rebound effect (*i.e.*, the increase in VMT attributed to an increase in fuel efficiency).

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.[310],[311] Finally, 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.

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[308] Source: Sorrell and Dimitropolous (2007), Table VIII-3, and the agencies' addition of Pickrell & Schimek (1999).

[309] 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.

[310] Six of the household survey studies evaluated in Table VIII-2 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.

[311] The four studies with rebound estimates that increase with higher household vehicle ownership: Greene & Hu; Hensher et al.; Wall et al.; and West & Pickrell. The two studies with rebound estimates that decrease with higher household vehicle ownership: Mannering and Winston; and Greene et al. (note that Greene et al. showed decreases in the rebound effect as households went from 1 to 2 and from 2 to 3 vehicles, then a slight increase from 3 to 4 vehicles; the rebound estimate for households with 4 vehicles was lower than for households with 2 vehicles).

In order to provide a more comprehensive overview of previous estimates of the rebound effect, EPA and NHTSA reviewed 22 studies of the rebound effect conducted from 1983 through 2005. The agencies 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 VIII-4 below.[312] 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.

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[312] 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.

Table VIII-4

Summary Statistics for Estimates of the Rebound Effect

Category of Estimates	**Number of Studies**	**Number of Estimates**	**Range**		**Distribution**		
			Low	**High**	**Median**	**Mean**	**Std. Dev.**
All Estimates	23	72	7%	75%	21%	23%	13%
Published Estimates	17	50	7%	75%	22%	24%	14%
Authors' Preferred Estimates	17	17	9%	75%	22%	22%	15%
U.S. Time-Series Estimates	7	34	7%	45%	14%	18%	9%
Household Survey Estimates	13	23	9%	75%	31%	31%	16%
Pooled U.S. State Estimates	3	15	8%	58%	22%	23%	12%
Constant Rebound Effect (1)	15	37	7%	75%	20%	23%	16%
Variable Rebound Effect (1) Reported Estimates	10	29	10%	45%	23%	23%	10%
Updated to 2010 (2)	11	33	6%	56%	15%	19%	13%

(1) Three studies estimate both constant and variable rebound effects.

(2) Reported estimates updated to reflect 2010 values of vehicle use, fuel prices, fleet fuel efficiency, household income, and household vehicle ownership.

Summary of Recent Studies and Analyses of the Rebound Effect

More recent studies since 2007 indicate that the rebound effect has decreased over time as incomes have generally increased and, until recently, fuel costs as a share of total monetary travel costs have generally decreased.[313] 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

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[313] 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 (2010)). 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 dependant on income than fuel costs. A third study, Greene (2010), did not directly test the effect of fuel cost on rebound, but found evidence supporting the strong effect from income. Although several studies have shown that the rebound effect rises with household vehicle ownership (see section 4.2.5.1), which has generally increased with income, these findings indicate that income has had a negative effect on rebound.

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.[314] 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.[315] 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.[316]

In 2010, Hymel, Small and Van Dender extended the Small and Van Dender model by adding congestion as an endogenous variable.[317] Although controlling for congestion significantly increased their estimates of the rebound effect, Hymel, Small and Van Dender 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.[318] 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

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[314] 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.

[315] 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.

[316] 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 (Docket EPA-HQ-OAR-XXX).

[317] 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.

[318] Greene, David, "Rebound 2007: Analysis of National Light-Duty Vehicle Travel Statistics," February 9, 2010. This paper has been accepted for an upcoming special issue of Energy Policy, although the publication date has not yet been determined.

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 2007, and drops to 10 percent in 2010, 9 percent in 2016 and 8 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 proposal, 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.[319] 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. Additional research is needed in this area, and the agencies request comments and data on this topic.

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.[320,321] 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.[322] 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 proposed 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. More research in this area is also important, and the agencies invite comment on this aspect of the rebound effect.

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[319] Gillingham, Kenneth. "The Consumer Response to Gasoline Price Changes: Empirical Evidence and Policy Implications." Ph.D. diss., Stanford University, 2011.

[320] Dargay, J.M.,Gately,D.,1997. The demand for transportation fuels: imperfect price-reversibility? Transportation Research PartB 31(1).

[321] Sentenac-Chemin, E. (2010) Is the price effect on fuel consumption symmetric? Some evidence from an empirical study, Energy Policy (2010), doi:10.1016/j.enpol.2010.07.016

[322] Dermot Gately, 1993. "The Imperfect Price-Reversibility of World Oil Demand," The Energy Journal, International Association for Energy Economics, vol. 14(4), pages 163-182.

NHTSA Analysis of the Rebound Effect

To provide additional insight into the rebound effect for the purposes of this rulemaking, NHTSA developed several new estimates of its magnitude. These estimates were developed by estimating and testing several econometric models of the relationship between vehicle miles-traveled and factors that influence it, including household income, fuel prices, vehicle fuel efficiency, road supply, the number of vehicles in use, vehicle prices, and other factors.

As the 2007 study by Small and Van Dender pointed out, it is important to account for the effect of fuel prices when attempting to estimate the rebound effect. Failing to control for changes in fuel prices is likely to bias estimates of the rebound effect. Therefore, changes in fuel prices are taken into account in NHTSA's analysis of the rebound effect. Several different approaches were used to estimate the fuel economy rebound effect for light duty vehicles, many of which attempt to account for the endogenous relationship of fuel efficiency to fuel prices.

The results from each of these approaches are presented in Table VIII-5 below. Table VIII-5 reports the value of the rebound effect calculated over the entire period from 1950 through 2006, as well as for the final year of that period. In addition, the table presents forecasts of the average rebound effect between 2010 and 2030, which utilize forecasts of personal income, fuel prices, and fuel efficiency from EIA's AEO 2011 Reference Case.

The results of NHTSA's analysis are broadly consistent with the findings from previous research summarized above. The historical average long-run rebound effect is estimated to range from 16-30 percent, and comparing these estimates to its calculated values for 2006 (which range from 8-14 percent) gives some an indication that it is declining in magnitude. The forecast values of the rebound effect shown in the table also suggest that this decline is likely to continue through 2030, as they range from 4-16 percent.

Table VIII-5

Summary of NHTSA Estimates of the Rebound Effect

Model	**VMT Measure**	**Variables Included in VMT Equation**	**Estimation Technique**	**Rebound Effects:**		
				1950-2006	**2006**	**2010-2030***
Small-Van Dender single VMT equation	annual VMT per adult	fuel cost per mile, per Capita income, vehicle stock, road miles per adult, fraction of population that is adult, fraction of population living in urban areas, fraction of population living in urban areas with heavy rail, dummy variables for fuel rationing, time trend	OLS	33.0%	15.8%	8.0%
Small-Van Dender three-equation system	annual VMT per adult	fuel cost per mile, per Capita income, vehicle stock, road miles per adult, fraction of population that is adult, fraction of population living in urban areas, fraction of population living in urban areas with heavy rail, dummy variables for fuel rationing, time trend	3SLS	21.6%	5.8%	3.4%
Single-equation VMT model	annual VMT per adult	personal income, road miles per Capita, time trend	OLS	18.4%	11.7%	9.2%
Single-equation VMT model	annual VMT per vehicle	fuel cost per mile, personal income, road miles per Capita, time trend	OLS	17.6%	15.2%	15.7%
Single-equation VMT model	annual VMT per adult	fuel cost per mile, personal income, road miles per Capita, dummy variables for fuel	OLS	34.0%	20.8%	13.6%

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 conducted by EPA and NHTSA, an estimate of 10 percent for the rebound effect was used for this proposal (*i.e.*, we assume a 10 percent decrease in fuel cost per mile from our proposed standards would result in a 1 percent increase in VMT), with a range of 5-20 percent for use in NHTSA's sensitivity testing.

As Tables VIII-1, VIII-2, VIII-3, and VIII-4 indicate, the 10 percent figure is on the low end of the range reported in previous research, and Table VIII-5 shows that it is also below most estimates of the historical and current magnitude of the rebound effect developed by NHTSA. However, other recent research – particularly that conducted by Hymel, Small and Van Dender, Small and Van Dender, and Greene – reports persuasive evidence that the magnitude of the rebound effect is likely to be declining over time, and the forecasts developed by NHTSA and reported in Table VIII-5 also suggest that this is likely to be the case. Furthermore, for the reasons described above (see "summary of recent studies of the rebound effect") , historical estimates of the rebound effect may overstate the magnitude of a change in a small, gradual decrease in the cost of driving due to our proposed standards. Finally, new research by Gillingham suggests that consumers may be more responsive to changes in gasoline prices than to changes in fuel efficiency, and that the rebound effect that occurs when consumers purchase more efficient vehicles as a result of a policy may be on the order of 6 percent.

As a consequence, the agencies concluded that a value on the low end of the historical estimates reported in Tables VIII-1, VIII-2, VIII-3, and VIII-4 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 proposal. The 10 percent estimate lies within the 10-30 percent range of estimates for the historical rebound effect reported in most previous 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. As Table VIII-5 shows, it also lies within the 3-16 percent range of forecasts of the future magnitude of the rebound effect developed by NHTSA in its recent research. 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.

On-Road Fuel Economy Adjustment

Actual fuel economy levels achieved by vehicles in on-road driving fall significantly short of their levels measured under the laboratory-like test conditions used by EPA to establish its published fuel economy ratings for different models. In analyzing the fuel savings from alternative passenger car and light truck CAFE standards, the agency adjusts the actual fuel economy performance of each passenger car and light truck model downward from its rated value to reflect the expected size of this on-road fuel economy "gap." In December 2006, EPA adopted changes to its regulations on fuel economy labeling, which were intended to bring vehicles' rated fuel economy levels closer to their actual on-road fuel economy levels.[323]

Supplemental analysis reported by EPA as part of its Final Rule indicates that actual on-road fuel economy for light-duty vehicles averages 20 percent lower than published fuel economy levels.[324] 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). The agency has employed EPA's revised estimate of this on-road fuel economy gap in its analysis of the fuel savings resulting from alternative CAFE standards for MY 2017-2025 passenger cars and light trucks.

An analysis conducted by NHTSA confirmed that EPA's estimate of a 20 percent gap between test and on-road fuel economy is well-founded. The agency 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.

B. Benefits to Vehicle Buyers from Improving Fuel Economy

The main source of economic benefits from raising CAFE standards is the value of the resulting fuel savings over the lifetimes of vehicles that are required to achieve higher fuel economy. The annual fuel savings under each alternative CAFE standard are measured by the difference between total annual fuel consumption by passenger cars or light trucks with the fuel economy they are expected to achieve in on-road driving under that alternative standard, and their annual fuel consumption with the fuel economy levels – again adjusted for differences between test and actual on-road driving conditions – they would achieve under the baseline alternative. The sum of these annual fuel savings over each calendar year that cars or light trucks produced during a

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[323] EPA, Fuel Economy Labeling of Motor Vehicles: Revisions To Improve Calculation of Fuel Economy Estimates; Final Rule, 40 CFR Parts 86 and 600, Federal Register, December 27, 2006, pp. 77872-77969, http://www.epa.gov/fedrgstr/EPA-AIR/2006/December/Day-27/a9749.pdf (last accessed on March 15, 2010).

[324] 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 (last accessed on March 15, 2010).

model year are expected to remain in service represents their cumulative lifetime fuel savings with that alternative CAFE standard in effect.

Vehicle Survival Rates

These annual fuel savings depend on the number of vehicles that remain in use during each year of a model year's lifetimes. The number of passenger cars or light trucks manufactured during a model year that remains in service during each subsequent calendar year is estimated by multiplying the original number expected to be produced during that model year by the proportion of vehicles expected to remain in service to the age they will have reached during that year. The proportions of passenger cars and light trucks expected to remain in service at each age up to their maximum lifetimes (26 and 36 years, respectively) are shown in Table VIII-6.[325] These "survival rates," which are estimated from experience with recent model-year vehicles, are slightly different than the survival rates used in past NHTSA analyses, since they reflect recent increases in durability and usage of more recent passenger car and light truck models.[326]

Vehicle Use

Annual fuel savings during each year of a model year's lifetime also depend on the number of miles that the remaining vehicles in use are driven. Updated estimates of average annual miles driven by age were developed by NHTSA for MY 2011 rulemaking from the Federal Highway Administration's 2001 National Household Transportation Survey, and these also differ from the estimates of annual mileage employed in past NHTSA analyses.[327] Table VIII-7 reports NHTSA's updated estimates of average car and light truck use. The ***total*** number of miles driven by passenger cars or light trucks produced during a model year are driven during each year of its lifetime is estimated by multiplying these age-specific estimates of average car and light truck use by the number of vehicles projected to remain in service during that year.

A summation of the values in Table VIII-7 of survival-weighted mileage over the 26-year maximum lifetime of passenger cars is 161,847 miles, while that over the 36-year maximum lifetime of light trucks is 190,066 miles. Fuel savings and other benefits resulting from higher CAFE standards for passenger cars and light trucks are calculated over their respective lifetimes

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[325] The maximum age of cars and light trucks was defined as the age when the number remaining in service has declined to approximately two percent of those originally produced. Based on an examination of recent registration data for previous model years, typical maximum ages appear to be 26 years for passenger cars and 36 years for light trucks.

[326] The survival rates were calculated from R.L. Polk, National Vehicle Population Profile (NVPP), 1977-2003; see NHTSA, "Vehicle Survival and Travel Mileage Schedules," Office of Regulatory Analysis and Evaluation, NCSA, January 2006, pp. 9-11, Docket No. 22223-2218. Polk's NVPP is an annual census of passenger cars and light trucks registered for on-road operation in the United States as of Jul 1 each year. NVPP registration data from vehicle model years 1977 to 2003 were used to develop the survival rates reported in Table VIII-6. Survival rates were averaged for the five most recent model years for vehicles up to 20 years old, and regression models were fitted to these data to develop smooth relationships between age and the proportion of cars or light trucks surviving to that age.

[327] See also NHTSA, "Vehicle Survival and Travel Mileage Schedules," Office of Regulatory Analysis and Evaluation, January 2006, pp. 15-17 (Docket NHTSA-2009-0062-0012.1). The original source of information on annual use of passenger cars and light trucks by age used in this analysis is the 2001 National Household Travel Survey (NHTS), jointly sponsored by the Federal Highway Administration, Bureau of Transportation Statistics, and National Highway Traffic Safety Administration.

and total expected mileage. It should be noted, however, that survival-weighted mileage is extremely low (less than 1,000 miles per year) after age 20 for cars and after age 25 for light trucks, and thus has little impact on lifetime fuel savings or other benefits from higher fuel economy, particularly after discounting those benefits to their present values.

In interpreting the survival and annual mileage estimates reported in Table VIII-7, it is important to understand that vehicles are considered 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 typical are first offered for sale in June through September of the preceding 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.[328]

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[328] As an illustration, virtually the entire production of model year 2017 cars and light trucks will have been sold by the end of calendar year 2017, so those vehicles are defined to be of age 1 during calendar year 2017. Model year 2017 vehicles are subsequently defined to be of age 2 during calendar year 2018, age 3 during calendar year 2019, and so on. One complication arises because registration data are typically collected for July 1 of each calendar year, so not all vehicles produced during a model year will appear in registration data until the calendar year when they have reached age 2 (and sometimes age 3) under this convention.

Table VIII-6
Survival Rates by Age
for Passenger Cars and Light Trucks

Vehicle Age	Estimated Survival Fraction Passenger Cars	Estimated Survival Fraction Light Trucks
1	0.9950	0.9950
2	0.9900	0.9741
3	0.9831	0.9603
4	0.9731	0.9420
5	0.9593	0.9190
6	0.9413	0.8913
7	0.9188	0.8590
8	0.8918	0.8226
9	0.8604	0.7827
10	0.8252	0.7401
11	0.7866	0.6956
12	0.7170	0.6501
13	0.6125	0.6042
14	0.5094	0.5517
15	0.4142	0.5009
16	0.3308	0.4522
17	0.2604	0.4062
18	0.2028	0.3633
19	0.1565	0.3236
20	0.1200	0.2873
21	0.0916	0.2542
22	0.0696	0.2244
23	0.0527	0.1975
24	0.0399	0.1735
25	0.0301	0.1522
26	0.0227	0.1332
27		0.1165
28		0.1017
29		0.0887
30		0.0773
31		0.0673
32		0.0586
33		0.0509
34		0.0443
35		0.0385
36		0.0334

Adjusting Vehicle Use

The estimated average annual miles driven by passenger cars and light trucks changes every year in the Volpe model depending upon the real price of gasoline. The baseline for determining the miles traveled by age of the vehicle and the appropriate price of gasoline was developed at the time the 2001 National Household Travel Survey (NHTS) was conducted. To account for the effect on vehicle use of subsequent increases in fuel prices, the estimates of annual vehicle use derived from the NHTS were adjusted to reflect the forecasts of future gasoline prices reported in the ***AEO 2011***. This adjustment accounts for the difference between the average price per gallon of fuel forecast for each year over the expected lifetimes of model year 2017-2025 passenger cars and light trucks, and the average price that prevailed when the NHTS was conducted in 2001. The elasticity of annual vehicle use with respect to fuel cost per mile corresponding to the 10% fuel economy rebound effect used in this analysis (i.e., an elasticity of -0.10) was applied to the percent difference between each future year's fuel prices and those prevailing in 2001 to adjust the estimates of vehicle use derived from the NHTS to reflect the effect of higher future fuel prices. This procedure was applied to the mileage figures to adjust annual mileage by age during each calendar year of the expected lifetimes of MY 2017-2025 cars and light trucks.

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 vehicle use. 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 represent an important 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.[329] During that time, however, the total number of passenger cars registered for in the U.S. grew by only about 0.3 percent annually.[330] 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.[331] Further, the AEO 2011 Reference Case forecasts 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 gradually from 2010 through 2030. For this analysis, annual growth in vehicle miles traveled was assumed to be 1.1% per year until year 2030 and then 0.5% annual growth per year after year 2030. Thus, there are a large number of VMT schedules used in the Volpe model, changing each year and changing by alternative because of the rebound effect. Table VIII-7 shows an example of the VMT schedules for passenger cars and light trucks for 2017.

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[329] Calculated from data reported in 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 March 15, 2010).

[330] 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.

[331] *See supra* note [2 above here]

Table VIII-7
Example Annual Vehicle-Miles Traveled (VMT) by Age for Passenger Cars and Light Trucks

Vehicle Age	Example VMT Passenger Cars	Example VMT Light Trucks
1	16,219	18,368
2	16,062	18,122
3	15,873	17,926
4	15,605	17,629
5	15,373	17,368
6	15,091	16,963
7	14,796	16,617
8	14,487	16,149
9	14,151	15,690
10	13,839	15,250
11	13,430	14,706
12	13,093	14,277
13	12,676	13,752
14	12,299	13,264
15	11,886	12,690
16	11,475	12,185
17	11,087	11,747
18	10,712	11,275
19	10,336	10,818
20	9,939	10,420
21	9,606	10,080
22	9,336	9,869
23	9,197	9,621
24	8,916	9,612
25	8,720	9,449
26	8,525	9,466
27		9,536
28		9,584
29		9,632
30		9,680
31		9,728
32		9,777
33		9,826
34		9,875
35		9,924
36		9,974

Estimating Annual Fuel Consumption

NHTSA estimated annual fuel consumption during each year of the expected lifetimes of model year 2017-2025 cars and light trucks with alternative CAFE standards in effect by dividing the total number of miles that a model year's surviving vehicles are driven by the fuel economy that they are expected to achieve under each alternative standard.[332] Lifetime fuel consumption by each model year's cars and light trucks is the sum of the annual use by the vehicles produced during that model year that are projected to remain in service during each year of their expected lifetimes. In turn, the *savings* in lifetime fuel consumption by MY 2017-2025 cars and light trucks that would result from alternative increases in CAFE standards is the difference between their lifetime fuel use at the fuel economy level they are projected to attain under the baseline, and their lifetime fuel use at the higher fuel economy level they are projected to achieve under each alternative standard.

NHTSA's analysis values the economic benefits to vehicle owners and to the U.S. economy that result from future fuel savings over the full expected lifetimes of MY 2017-2025 passenger cars and light trucks. This reflects the agency's assumption that while the purchasers of new vehicles might not realize the full lifetime benefits of improved fuel economy, subsequent owners of those vehicles will continue to experience the resulting fuel savings until they are retired from service. Of course, not all vehicles produced during a model year remain in service for the complete lifetimes (26 years for passenger cars or 36 years for light trucks) of each model year. Due to the pattern of vehicle retirements with increasing age, the expected or average lifetimes of typical representative cars and light trucks are approximately half of these figures.

Economic Benefits from Reduced Fuel Consumption

The economic value of fuel savings resulting from alternative CAFE standards is estimated by applying the Reference Case forecast of future fuel prices from the Energy Information Administration's Annual Energy Outlook 2011 to each future year's estimated fuel savings. The AEO 2011 Reference Case forecast of future fuel prices, which is reported in Table VIII-8a, represents retail prices per gallon of fuel, including federal, state, and any applicable local taxes. While the retail price of fuel is the proper measure for valuing fuel savings from the perspective of *vehicle owners*, two adjustments to the retail prices are necessary in order to accurately reflect the economic value of fuel savings to *the U.S. economy*.

First, federal, state, and local taxes are excluded from the social value of fuel savings because these do not reflect costs of resources used in fuel production, and thus do not reflect resource savings that would result from reducing fuel consumption. Instead, fuel taxes simply represent resources that are transferred from purchasers of fuel to road and highway users, since fuel taxes primarily fund construction and maintenance of those facilities. Any reduction in local, state, or federal fuel tax payments by fuel purchasers will reduce government revenues by the same amount, thus ultimately reducing the value of government-financed services by approximately that same amount. The benefit derived from lower taxes to individuals is thus likely to be offset exactly by a reduction in the value of services funded using those tax revenues.

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[332] The total number of miles that vehicles are driven each year is slightly different under each alternative as a result of the fuel economy "rebound effect," which is discussed in detail elsewhere in this chapter.

Second, the economic cost of externalities generated by U.S. consumption and imports of petroleum products will be reduced in proportion to fuel savings resulting from higher CAFE standards. The estimated economic value of these externalities, which is discussed in detail in the subsequent section of this Chapter, is converted into its per-gallon equivalent and added to the pre-tax price of gasoline in order to measure this additional benefit to society for each gallon of fuel saved. This also allows the magnitude of these externalities to be easily compared to the value of the resources saved by reducing fuel production and use, which represents the most important component of the social benefits from saving gasoline.

Table VIII-8a illustrates the adjustment of forecast retail fuel prices to remove the value of fuel taxes and add the value of economic externalities from petroleum imports and use. While the Reference Case fuel price forecasts reported in AEO 2011 extend through 2035, the agency's analysis of the value of fuel savings over the lifetimes of MY 2017-2025 cars and light trucks requires forecasts extending through calendar year 2060, approximately the last year during which a significant number of MY 2025 vehicles will remain in service.[333] To obtain fuel price forecasts for the years 2036 through 2060, the agency assumes that retail fuel prices will continue to increase after 2035 at the average rates reported in the AEO 2011 Reference Case forecast over the period from 2025 through 2035 (in constant-dollar terms).[334] As Table VIII-8a shows, the projected retail price (including taxes) of gasoline expressed in 2009 dollars rises steadily over the forecast period, from $2.80 in 2011 to $4.16 in 2060.

The agency has updated its estimates of gasoline taxes (all expressed in 2009 dollars) for federal taxes ($0.184 per gallon) state taxes ($0.22 per gallon), and local taxes ($0.02 per gallon), consistent with tax rates used by EIA in AEO 2011. NHTSA followed EIA's assumptions that state and local gasoline taxes are assumed to keep pace with inflation in nominal terms, and thus to remain at current levels when expressed in constant 2009 dollars. Federal gasoline taxes, however, are forecasted by EIA to remain unchanged in *nominal* terms, and thus decline throughout the forecast period when expressed in constant 2009 dollars. NHTSA also incorporated this assumption in its projections. These differing assumptions about the likely future behavior of federal and state/local fuel taxes are consistent with recent historical experience, which reflects the fact that federal motor fuel taxes as well as most state and local fuel taxes are specified on a cents-per-gallon basis (some state taxes are levied as a percentage of the wholesale price of fuel), and typically require legislation to change.

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[333] The agency 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-duty trucks, for example, this age has typically been 36 years for recent model years.

[334] This projection uses the rate of increase in fuel prices for 2020-2030 rather than that over the complete forecast period (2011-2030) because there is extreme volatility in the forecasts for the years 2011 through approximately 2020. Using the average rate of change over the complete 2011-2030 forecast period would result in projections of declining fuel prices after 2030.

Table VIII-8a
Adjustment of Forecast Retail Gasoline Prices to Reflect the Economic Value of Fuel Savings

Year	AEO 2011 Forecast of Retail Gasoline Price	Estimated Federal, State, and Local Taxes	Forecast Gasoline Price Excluding Taxes
	(2009 $/gallon)	(2009 $/gallon)	(2009 $/gallon)
2011	$2.80	$0.42	$2.38
2012	$2.82	$0.41	$2.41
2013	$2.97	$0.41	$2.56
2014	$3.06	$0.41	$2.65
2015	$3.13	$0.40	$2.73
2016	$3.18	$0.40	$2.78
2017	$3.25	$0.40	$2.85
2018	$3.30	$0.39	$2.91
2019	$3.34	$0.39	$2.95
2020	$3.38	$0.39	$2.99
2021	$3.39	$0.38	$3.01
2022	$3.45	$0.38	$3.07
2023	$3.47	$0.38	$3.09
2024	$3.52	$0.38	$3.14
2025	$3.54	$0.37	$3.17
2026	$3.56	$0.37	$3.19
2027	$3.62	$0.37	$3.25
2028	$3.63	$0.37	$3.26
2029	$3.68	$0.37	$3.31
2030	$3.64	$0.36	$3.28
2031	$3.64	$0.36	$3.28
2032	$3.65	$0.36	$3.29
2033	$3.66	$0.36	$3.30
2034	$3.69	$0.35	$3.34
2035	$3.71	$0.35	$3.36
2036	$3.72	$0.35	$3.38
2037	$3.74	$0.35	$3.40
2038	$3.76	$0.34	$3.41
2039	$3.78	$0.34	$3.43
2040	$3.79	$0.34	$3.45
2041	$3.81	$0.34	$3.47
2042	$3.83	$0.34	$3.49
2043	$3.85	$0.33	$3.51
2044	$3.87	$0.33	$3.53
2045	$3.88	$0.33	$3.55

2046	$3.90	$0.33	$3.57
2047	$3.92	$0.33	$3.59
2048	$3.94	$0.33	$3.61
2049	$3.96	$0.32	$3.63
2050	$3.97	$0.32	$3.65
2051	$3.99	$0.32	$3.67
2052	$4.01	$0.32	$3.69
2053	$4.03	$0.32	$3.71
2054	$4.05	$0.31	$3.73
2055	$4.07	$0.31	$3.75
2056	$4.09	$0.31	$3.77
2057	$4.11	$0.31	$3.80
2058	$4.12	$0.31	$3.82
2059	$4.14	$0.31	$3.84
2060	$4.16	$0.30	$3.86

Impact of Increased Fuel Economy on Fuel Tax Revenues

While NHTSA excludes fuel taxes from the estimation of net social benefits due to the fact that taxes are transfer payments, the agency recognizes the importance of fuel tax revenue in policymakers' budgetary decisions. By applying projected fuel tax rates to estimates of gallons of fuel saved for each of the calendar years in which vehicles of model years covered by this rule are expected to remain on the road, the agency developed an approximate schedule shown in Table VIII-8b of the net changes in fuel tax revenue under the preferred alternative at federal, state, and local levels. The projections in Table VIII-8b are consistent with the aforementioned AEO assumptions regarding the relationship of real future fuel tax rates to their present levels.

Table VIII-8b
Projected Annual Net Decrease in Fuel Tax Revenue Resulting From Proposed MY 2017-2025 CAFE Standards
(Millions of 2009$, Discounted 3%)

Year	Federal	State	Local
2017	$37	$50	$5
2018	$105	$154	$14
2019	$229	$335	$30
2020	$391	$574	$52
2021	$554	$871	$79
2022	$760	$1,195	$109
2023	$993	$1,561	$142
2024	$1,251	$1,965	$179
2025	$1,435	$2,428	$221
2026	$1,347	$2,279	$207
2027	$1,255	$2,124	$193
2028	$1,168	$1,976	$180
2029	$1,072	$1,814	$165
2030	$901	$1,653	$150
2031	$812	$1,489	$135
2032	$720	$1,320	$120
2033	$630	$1,155	$105
2034	$498	$996	$91
2035	$422	$843	$77
2036	$344	$700	$64
2037	$275	$569	$52
2038	$218	$458	$42
2039	$171	$366	$33
2040	$134	$292	$27
2041	$106	$233	$21
2042	$83	$186	$17
2043	$65	$149	$14
2044	$52	$120	$11
2045	$41	$97	$9
2046	$33	$79	$7
2047	$27	$65	$6
2048	$21	$53	$5
2049	$17	$43	$4
2050	$14	$36	$3

2051	$11	$29	$3
2052	$9	$25	$2
2053	$8	$21	$2
2054	$6	$17	$2
2055	$5	$14	$1
2056	$4	$11	$1
2057	$3	$8	$1
2058	$2	$6	$1
2059	$1	$4	$0
2060	$1	$2	$0
Total	**$16,231**	**$28,367**	**$2,579**

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. As evidenced by the fact that they 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 it consumes (measured at the improved level of fuel economy resulting from stricter CAFE standards).[335] The amount by which the benefits from this increased driving travel exceed its increased fuel costs measures the net benefits they receive from the additional travel, usually are referred to as increased consumer surplus.

NHTSA's 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 CAFE standards. Under even those alternatives that would impose the highest standards, however, the magnitude of benefits from additional vehicle use represents a small fraction of the total benefits from requiring cars and light trucks to achieve higher fuel economy.

Benefits due to reduced refueling time:

No direct estimates of the value of extended vehicle range are readily available, so the agency instead calculates the reduction in the required annual number of refueling cycles due to improved fuel economy, and assesses 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.

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[335] These benefits are included in the value of fuel savings reported throughout this analysis.

The agency calculates the economic value of refueling time savings by applying DOT-recommended values of travel time savings to estimates of how much time is saved.[336] The value of travel time depends on average hourly valuations of personal and business time, which are functions of total hourly compensation costs to employers. The total hourly compensation cost to employers, inclusive of benefits, in 2009$ is $29.37.[337] Table VIII-9 demonstrates the agency's approach to estimating the value of travel time ($/hour) for both urban and rural (intercity) driving. This approach relies on the use of DOT-recommended weights that assign a lesser valuation to personal travel time than to business travel time, as well as weights that adjust for the distribution between personal and business travel.

Table VIII-9
Estimating the Value of Travel Time For Urban and Rural (Intercity) Travel ($/hour)

Urban Travel			
	Personal travel	**Business Travel**	**Total**
Wage Rate ($/hour)	$29.37	$29.37	--
DOT-Recommended Value of Travel Time Savings, as % of Wage Rate	50%	100%	--
Hourly Valuation (=Wage Rate * DOT-Recommended Value)	$14.69	$29.37	--
% of Total Urban Travel	94.4%	5.6%	100%
Hourly Valuation (Adjusted for % of Total Urban Travel)	$13.86	$1.64	**$15.50**
Rural (Intercity) Travel			
	Personal travel	**Business Travel**	**Total**
Wage Rate ($/hour)	$29.37	$29.37	--
DOT-Recommended Value of Travel Time Savings, as % of Wage Rate	70%	100%	--
Hourly Valuation (=Wage Rate * DOT-Recommended Value)	$20.56	$29.37	--
% of Total Rural Travel	87.0%	13.0%	100%
Hourly Valuation (Adjusted for % of Total Rural Travel)	$17.89	$3.82	**$21.71**

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[336] See http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf and http://ostpxweb.dot.gov/policy/Data/VOTrevision1_2-11-03.pdf (last accessed 07/18/2011).

[337] Total hourly employer compensation costs for 2009 (average of quarterly observations). See http://www.bls.gov/ect/. NHTSA previously used a value of $25.50 for the total hourly compensation cost (*see*, *e.g.*, 75 FR at 25588, fn. 619) during 2008 expressed in 2007$. This earlier figure is deprecated by the availability of more current economic data.

The estimates of the hourly value of urban and rural travel time ($15.50 and $21.71, respectively) shown in Table VIII-9 must be adjusted to account for the nationwide ratio of urban to rural driving. By applying this adjustment (as shown in Table VIII-10), an overall estimate of the hourly value of travel time – independent of urban or rural status – may be produced. Note that up to this point, all calculations discussed assume only one adult occupant per vehicle. To fully estimate the average value of vehicle travel time, the agency must account for the presence of additional adult passengers during refueling trips. NHTSA applies such an adjustment as shown in Table VIII-10; this adjustment is performed separately for passenger cars and for light trucks, yielding occupancy-adjusted valuations of vehicle travel time during refueling trips for each fleet.

Table VIII-10
Estimating the Value of Travel Time for Light-Duty Vehicles ($/hour)

	Unweighted Value of Travel Time ($/hour)	**Weight (% of Total Miles Driven)[338]**	**Weighted Value of Travel Time ($/hour)**
Urban Travel	$15.50	66.5%	$10.31
Rural Travel	$21.71	33.5%	$7.27
Total	--	100.0%	$17.58

	Passenger Cars	**Light Trucks**
Average Vehicle Occupancy During Refueling Trips (persons)[339]	1.21	1.23
Weighted Value of Travel Time ($/hour)	$17.58	$17.58
Occupancy-Adjusted Value of Vehicle Travel Time During Refueling Trips ($/hour)	**$21.27**	**$21.62**

The agency estimated the amount of refueling time saved using (preliminary) survey data gathered as part of our 2010-2011 National Automotive Sampling System's Tire Pressure Monitoring System (TPMS) study.[340] The study was conducted at fueling stations nationwide,

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[338] Weights used for urban vs. rural travel are computed using cumulative 2009 estimates of urban vs. rural miles driven provided by the Federal Highway Administration. *Available at* http://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm (last accessed 07/18/2011).

[339] Source: National Automotive Sampling System 2010-2011 Tire Pressure Monitoring System (TPMS) study. See next page for further background on the TPMS study. TPMS data are preliminary at this time and rates are subject to change pending availability of finalized TPMS data. Average occupancy rates shown here are specific to refueling trips, and do not include children under 16 years of age.

[340] TPMS data are preliminary and not yet published. Estimates derived from TPMS data are therefore preliminary and subject to change. Observational and interview data are from distinct subsamples, each consisting of approximately 7,000 vehicles. For more information on the National Automotive Sampling System and to access TPMS data when they are made available, see http://www.nhtsa.gov/NASS.

and researchers made observations regarding a variety of characteristics of thousands of individual fueling station visits from August, 2010 through April, 2011.[341] Among these characteristics of fueling station visits is the total amount of time spent pumping and paying for fuel. From a separate sample (also part of the TPMS study), researchers conducted interviews at the pump to gauge the distances that drivers travel in transit to and from fueling stations, how long that transit takes, and how many gallons of fuel are being purchased.

For purposes of NHTSA's PRIA for these proposed standards, the agency focused on the interview-based responses in which respondents indicated the primary reason for the refueling trip was due to a low reading on the gas gauge.[342] This restriction was imposed so as to exclude distortionary effects of those who refuel on a fixed (*e.g.*, weekly) schedule and may be unlikely to alter refueling patterns as a result of increased driving range. The relevant TPMS survey data on average refueling trip characteristics are presented below in Table VIII-11.

Table VIII-11
Average Refueling Trip Characteristics for Passenger Cars and Light Trucks

	Gallons of Fuel Purchased	**Round-Trip Distance to/from Fueling Station (miles)**	**Round-Trip Time to/from Fueling Station (minutes)**	**Time to Fill and Pay (minutes)**	**Total Time (minutes)**
Passenger Cars	9.8	0.97	2.28	4.10	6.38
Light Trucks	13.0	1.08	2.53	4.30	6.83

As an illustration of how we estimate the value of extended refueling range, assume a small light truck model has an average fuel tank size of approximately 20 gallons, and a baseline actual on-road fuel economy of 24 mpg (its assumed level in the absence of a higher CAFE standard for the given model year). TPMS survey data indicate that drivers who indicated the primary reason for their refueling trips was a low reading on the gas gauge typically refuel when their tanks are 35 percent full (*i.e.*, 13.0 gallons as shown in Table VIII-11, with 7.0 gallons in reserve). By this measure, a typical driver would have an effective driving range of 312 miles (= 13.0 gallons x 24 mpg) before he or she is likely to refuel. Increasing this model's actual on-road fuel economy from 24 to 25 mpg would therefore extend its effective driving range to 325 miles (= 13.0 gallons x 25 mpg). Assuming that the truck is driven 12,000 miles/year,[343] this 1 mpg improvement in actual on-road fuel economy reduces the expected number of refueling trips per

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[341] The data collection period for the TPMS study ranged from 08/10/2010 to 04/15/2011.

[342] Approximately 60 percent of respondents indicated "gas tank low" as the primary reason for the refueling trip in question.

[343] Source of annual vehicle mileage: U.S. Department of Transportation, Federal Highway Administration, 2009 National Household Travel Survey (NHTS). See http://nhts.ornl.gov/2009/pub/stt.pdf (table 22, p.48). 12,000 miles/year is an approximation of a light duty vehicle's annual mileage during its initial decade of use (the period in which the bulk of benefits are realized). The VOLPE model estimates VMT by model year and vehicle age, taking into account the rebound effect, secular growth rates in VMT, and fleet survivability; these complexities are omitted in the above example for simplicity.

year from 38.5 (= 12,000 miles per year / 312 miles per refueling) to 36.9 (= 12,000 miles per year / 325 miles per refueling), or 1.6 refuelings per year. If a typical fueling cycle for a light truck requires a total of 6.83 minutes, then the annual value of time saved due to that 1 mpg improvement would amount to $3.94 (= (6.83/60) x $21.62 x 1.6).

In the analysis, we repeat this calculation for each future calendar year that light-duty vehicles of each model year affected by the alternative CAFE standards considered in this rule would remain in service. The resulting cumulative lifetime valuations of time savings account for both the reduction over time in the number of vehicles of a given model year that remain in service and the reduction in the number of miles (VMT) driven by those that stay in service. We also adjust the value of time savings that will occur in future years both to account for expected annual growth in real wages and to apply a discount rate to determine the net present value of time saved.[344] A final adjustment is made to account for evidence which suggests that 40 percent of refueling trips are for reasons other than a low reading on the gas gauge; it is therefore assumed that only 60 percent of the theoretical refueling time savings will be realized, as we assume that owners who refuel on a fixed schedule will continue to do. Results are calculated separately for a given model year's fleet of passenger cars and that year's fleet of light trucks. Valuations of both fleets' benefits are then summed to determine the benefit across all light-duty vehicles. This survey of refueling and our analysis of it will be peer reviewed in the future.

Tables VIII-12, VIII-13, and VIII-14 provide an illustration of the derivation of the lifetime net present value of refueling time savings for the MY 2017 fleet of passenger cars, assuming the rate of increase in fuel economy as per the preferred alternative relative to the baseline for the same model year. Tables VIII-12 and VIII-13 present the underlying assumptions behind the results presented in Table VIII-14. Note that this example is illustrative only; the CAFE model calculates this benefit at a combined (passenger car and light truck) level using the average of VMT-weighted parameters, after which the results are prorated to passenger car and light truck fleets, respectively. Additionally, the VMT schedule used in this example assumes that all vehicles sold in the given model year rely on ICE engines; in the CAFE model, the fleet contains a mix of vehicles utilizing alternate engine technologies that result in a variety of individualized VMT schedules. Due to these simplifications that were made to allow an empirical example, the results of this example cannot be compared to the actual CAFE model output of this benefit's value.

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[344] A 1.1 percent annual rate of growth in real wages is used to adjust the value of travel time per vehicle ($/hour) for future years for which a given model is expected to remain in service. This rate is supported by a BLS analysis of growth in real wages from 2000 – 2009. See http://www.bls.gov/opub/ted/2011/ted_20110224.htm.

Table VIII-12
Economic Values Used in Estimation of Lifetime Net Present Value of MY 2017 Passenger Car Refueling Time Savings

Sales of MY 2017 Passenger Cars:	9,987,667	Discount Rate:	7%
Achieved MPG, Preferred Alternative (with AC adjustment):	38.8	Achieved MPG, Baseline (with AC adjustment):	37.3
Actual On-Road MPG, Preferred Alternative:	31.0	Actual On-Road MPG, Baseline:	29.8
Average Fuel Tank Size (gallons):	15	Refueling Occurs When Tank Reaches (% capacity):	35%
Effective (pre-refueling) Driving Range, Preferred Alternative:	302.6	Effective (pre-refueling) Driving Range, Baseline:	290.9
Refueling Trips Due To Low Fuel Tank:	60%	Average Length of Refueling Trip (minutes):	6.38
Value of Passenger Car Vehicle-Hour Travel Time (2009$):	$21.27	Annual Real Wage Growth:	1.1%

Table VIII-13
Assumed Vehicle Survival Rates and VMT Schedules for MY 2017 Passenger Cars, Preferred Alternative vs. Baseline Scenario

Year	Vehicle Survival Rate	# of Surviving Vehicles	Annual VMT, Baseline (per-vehicle)	Annual VMT, Preferred Alternative (per-vehicle)	Fleetwide VMT, Baseline (millions of miles)	Fleetwide VMT, Preferred Alternative (millions of miles)
2017	0.995	9,937,728	16,007	16,092	159,070	159,920
2018	0.99	9,887,789	15,771	15,856	155,941	156,779
2019	0.9831	9,818,874	15,476	15,560	151,956	152,777
2020	0.9731	9,718,998	15,056	15,140	146,327	147,144
2021	0.9593	9,581,168	14,622	14,704	140,097	140,878
2022	0.9413	9,401,390	14,083	14,162	132,395	133,144
2023	0.9188	9,176,668	13,476	13,553	123,666	124,372
2024	0.8918	8,907,001	12,806	12,880	114,066	114,721
2025	0.8604	8,593,388	12,068	12,138	103,707	104,308
2026	0.8252	8,241,822	11,320	11,385	93,301	93,835
2027	0.7866	7,856,298	10,469	10,531	82,244	82,732
2028	0.717	7,161,157	9,303	9,358	66,622	67,014
2029	0.6125	6,117,445	7,693	7,739	47,059	47,344
2030	0.5094	5,087,717	6,207	6,245	31,580	31,772
2031	0.4142	4,136,891	4,878	4,907	20,180	20,301
2032	0.3308	3,303,920	3,762	3,784	12,428	12,502
2033	0.2604	2,600,788	2,862	2,878	7,442	7,485
2034	0.2028	2,025,499	2,154	2,166	4,362	4,387
2035	0.1565	1,563,070	1,604	1,613	2,507	2,521
2036	0.12	1,198,520	1,183	1,189	1,417	1,425
2037	0.0916	914,870	873	877	798	803
2038	0.0696	695,142	645	648	448	450
2039	0.0527	526,350	482	484	254	255
2040	0.0399	398,508	354	355	141	141
2041	0.0301	300,629	261	262	78	79
2042	0.0227	226,720	192	193	44	44

Table VIII-14
Estimation of Lifetime Net Present Value of Refueling Time Savings for MY 2017 Passenger Cars, Preferred Alternative vs. Baseline Scenario

Year	# of Refueling Trips, Baseline	# of Refueling Trips, Preferred Alternative	# of Fewer Refueling Trips Due To Higher CAFE Standard (x 60% adjustment)	# of Fewer Hours Spent Refueling	Value of Vehicle-hour travel time in given year (2009$)	Value of Time Saved (Discounted, 2009$)
2017	546,745,021	528,417,733	10,996,372	1,169,281	$23.09	$26,099,257
2018	535,989,998	518,036,403	10,772,157	1,145,439	$23.34	$24,157,321
2019	522,294,184	504,814,808	10,487,625	1,115,184	$23.60	$22,222,382
2020	502,945,856	486,201,640	10,046,530	1,068,281	$23.86	$20,113,929
2021	481,531,363	465,498,536	9,619,697	1,022,894	$24.12	$18,197,410
2022	455,060,633	439,943,058	9,070,545	964,501	$24.39	$16,212,461
2023	425,057,286	410,956,607	8,460,407	899,623	$24.66	$14,288,092
2024	392,061,455	379,066,850	7,796,763	829,056	$24.93	$12,441,269
2025	356,454,274	344,660,131	7,076,486	752,466	$25.20	$10,669,286
2026	320,687,563	310,054,909	6,379,592	678,363	$25.48	$9,088,203
2027	282,682,584	273,368,482	5,588,461	594,240	$25.76	$7,522,197
2028	228,990,359	221,430,268	4,536,055	482,334	$26.04	$5,768,968
2029	161,747,739	156,436,690	3,186,629	338,845	$26.33	$3,829,295
2030	108,544,332	104,983,084	2,136,749	227,208	$26.62	$2,426,096
2031	69,360,276	67,079,727	1,368,330	145,499	$26.91	$1,467,955
2032	42,716,359	41,308,849	844,506	89,799	$27.21	$856,036
2033	25,579,974	24,733,528	507,868	54,003	$27.51	$486,415
2034	14,993,822	14,495,242	299,148	31,809	$27.81	$270,714
2035	8,617,394	8,329,854	172,525	18,345	$28.11	$147,517
2036	4,871,408	4,709,085	97,394	10,356	$28.42	$78,685
2037	2,744,110	2,652,231	55,127	5,862	$28.74	$42,081
2038	1,540,645	1,488,504	31,285	3,327	$29.05	$22,565
2039	871,356	841,100	18,153	1,930	$29.37	$12,371
2040	484,309	467,451	10,115	1,076	$29.69	$6,513
2041	269,705	260,226	5,688	605	$30.02	$3,460
2042	149,997	144,700	3,178	338	$30.35	$1,827
Lifetime Net Present Value of Refueling Time Savings (2009$):						**$196,432,307**

Table VIII-13 demonstrates the progressive decrease over time in the value of future years' benefits due to the decline in the number of surviving vehicles, the reduction in miles that those vehicles are driven, and consumers' discounting of future benefits. About 90 percent of the lifetime net present value of this benefit is realized within the fleet's first decade of service, with the remaining additional benefit accruing through 2042.

To determine the lifetime benefit across all light duty vehicles, the calculations in the preceding tables are repeated for the given model year's light truck fleet, after which the benefits to both fleets may be summed to determine the lifetime net present value of refueling time savings for the entire light duty fleet. The estimated lifetime net present value of the benefit of refueling time savings for MY 2017 light trucks is $49,565,807 (2009$). Using this approach, the lifetime net benefit of refueling time savings for the entire MY 2017 light duty fleet is estimated at approximately $243,000,000 (2009$). As previously mentioned in the text preceding Table VIII-12, this value differs somewhat from the value of refueling time savings output by the Volpe model and is not intended to replicate the Volpe model output due to simplifications made for the sake of allowing this empirical example.

Since a reduction in the expected number of annual refueling trips leads to a decrease in miles driven to and from fueling stations, we can also calculate the value of consumers' fuel savings associated with this decrease. As shown in Table VIII-11, the typical incremental round-trip mileage per refueling cycle is 1.08 miles for light trucks and 0.97 miles for passenger cars. Going back to the earlier example of a light truck model, a decrease of 1.6 in the number of refuelings per year leads to a reduction of 1.73 miles driven per year (= 1.6 refuelings x 1.08 miles driven per refueling). Again, if this model's actual on-road fuel economy was 24 mpg, the reduction in miles driven yields an annual savings of approximately 0.07 gallons of fuel (= 1.73 miles / 24 mpg), which at $3.44/gallon[345] results in a savings of $0.25 per year to the owner. Note that this example is illustrative only of the approach NHTSA uses to quantify this benefit; in practice, the societal value of this benefit must exclude fuel taxes (as they are transfer payments) from the calculation, and must be modeled using fuel price forecasts specific to each year the given fleet will remain in service.

The annual savings to each consumer shown in the above example may seem like a small amount, but the reader should recognize that the valuation of the cumulative lifetime benefit of this savings to owners is determined separately for passenger car and light truck fleets and then aggregated to show the net benefit across all light-duty vehicles – which is much more significant at the macro level. Calculations of benefits realized in future years are adjusted for expected real growth in the price of gasoline, for the decline in the number of vehicles of a given model year that remain in service as they age, for the decrease in the number of miles (VMT) driven by those that stay in service, and for the percentage of refueling trips that occur for reasons other than a low reading on the gas gauge; a discount rate is also applied in the valuation of future benefits. Across the entire MY 2017 light-duty fleet, the aggregate value of this benefit

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[345] Estimate of $3.44/gallon is in 2009$. This figure is an average of forecasted cost per gallon (including taxes, as individual consumers consider reduced tax expenditures to be savings) for motor gasoline for years 2017 to 2027. Source of price forecasts: U.S. Energy Information Administration, Annual Energy Outlook 2011. See http://www.eia.gov/forecasts/aeo/source_oil.cfm (last accessed November 11, 2011).

over the fleet's lifetime is estimated at approximately $10,000,000 (2009$). NHTSA considered using this direct estimation approach to quantify the value of this benefit by model year, however the value of this benefit is implicitly captured in the separate measure of overall valuation of fuel savings, and therefore direct estimates of this benefit are not added to net benefits calculations.

We note that there are other benefits resulting from the reduction in miles driven to and from fueling stations, such as a reduction in greenhouse gas emissions – CO_2 in particular – and reduced wear on vehicles. However, estimates of the values of these benefits indicate that both are extremely minor in the context of the overall valuation of benefits associated with gains in vehicle driving range, so direct estimates of these additional benefits are not included within this analysis.

It is important to note that manufacturers' decisions regarding vehicles' fuel tank sizes are integral to the realized value of this benefit. In MY 2010, fuel tanks were sized such that average driving range of passenger cars was 410 miles and of light trucks was 430 miles. At vehicle redesign, manufacturers typically redesign fuel tanks based on changes in vehicle design and the allowable space for the fuel tank. At redesign, manufacturers consider driving range, cargo and passenger space (utility), mass targets, safety, and other factors. As fuel economy improves, manufacturers may opt at the time of vehicle redesign to downsize vehicles' fuel tanks as a mass-reduction strategy and to maintain a target maximum range consistent with previous models. Downsizing the fuel tank offers the potential for significant mass reduction[346] at a cost savings. It is also possible for manufacturers to reduce the effective size of their fuel tanks by changing the length of the fill tube, which does not require redesign of the tank itself. In determining the feasible amount of mass reduction and the cost for mass reduction, the agency assumed that fuel tanks would be resized to maintain range. The agency expects manufacturers will be more likely to downsize fuel tanks to maintain range than to increase range because of the stringency of the proposed standards, and the importance of mass reduction as an enabler for compliance. If a manufacturer did not downsize the fuel tank to maintain range, it would incur higher costs for compliance than projections indicate because the manufacturer would need to employ other higher cost technologies to achieve fuel economy and GHG improvements. If manufacturers elect to reduce fuel tank size in response to improved fuel economy to maintain range, the value of the refueling time savings benefit will be reduced because the number of trips to the gasoline station would not be reduced as much as estimated. Reductions to fuel tank size will not eliminate the value of the refueling time savings benefit, however, unless they are performed annually to maintain a constant range. Also, the reduced time for refueling and reduction in evaporative emissions would be unchanged. The agency believes that annual refreshes of fuel tank size during the years in-between model redesigns are unlikely; therefore, while downsizing fuel tanks would decrease the realized value of the refueling time savings benefit, it would not eliminate it, assuming that fuel economy rises in those interim years. NHTSA assumed a constant fuel tank size in estimating the impact of higher CAFE requirements on the frequency of refueling. NHTSA seeks comment regarding this assumption. Specifically, NHTSA seeks comment from manufacturers regarding their intention to retain fuel tank size or driving range in

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[346] For example, for a vehicle with a 15 gallon fuel tank and a 400 mile range, increasing fuel economy by 50% and downsizing the fuel tank to maintain range would enable a mass reduction of approximately 14 pounds based on the reduction in the amount of fuel alone. If the fuel tank was not downsized, the range of the vehicle would increase to 600 miles.

their redesigned vehicles. Will fuel economy improvements translate into increased driving range, or will fuel tanks be reduced in size to maintain current driving range?"

To the extent that manufacturers choose to increase driving range at redesigns during the rulemaking period, that decision would be made by the manufacturers independently of the proposed MY 2017-2025 CAFE standards. NHTSA does not attempt to project manufacturer's decisions related to increasing vehicle utility that are not required by the standards.

Special mention must be made with regard to the impact to consumers of changes in the driving range of electric vehicles (EVs). EV owners who routinely drive daily distances that do not require recharging on-the-go may eliminate the need for trips to fueling or charging stations. It is likely that early adopters of EVs will factor this benefit into their purchasing decisions and maintain driving patterns that require once-daily at-home recharging (a process which takes two to six hours for a full charge). However, EV owners who regularly or periodically need to drive distances further than the fully-charged EV range may need to recharge at fixed locations. A distributed network of charging stations (e.g., in parking lots, at parking meters) may allow some EV owners to recharge their vehicles while at work or while shopping, yet the lengthy charging cycles of current charging technology may pose a cost to owners due to the value of time spent waiting for EVs to charge. Moreover, EV owners who primarily recharge their vehicles at home will still experience some level of inconvenience due to their vehicle being either unavailable for unplanned use, or to its range being limited during this time should they interrupt the charging process. Therefore, at present EVs hold potential in offering significant time savings to owners with driving patterns optimally suited for EV characteristics. As fast-charging technologies improve and a widespread network of fast-charging stations is established, it is expected that a larger segment of EV vehicle owners will fully realize the potential refueling time savings benefits that EVs offer.

C. Other Economic Benefits from Reducing U.S. Petroleum Use

Reducing fuel use by requiring cars and light trucks to attain higher fuel economy 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, including reducing the price of petroleum, lowering the potential costs from disruption in the flow of oil imports, and possibly reducing outlays to support U.S. military activities to secure the flow of oil imports and to cushion the economy against their possible interruption by maintaining the Strategic Petroleum Reserve. Reducing fuel consumption also lowers the economic costs of environmental externalities resulting from fuel production and use, including reducing the impacts on human health impacts from emissions of criteria air pollutants, and reducing future economic damages from potential changes in the global climate caused by greenhouse gas emissions.

Economic Externalities from U.S. Petroleum Imports

U.S. consumption and imports of petroleum products imposes costs on the domestic economy that are not reflected in the market price for crude petroleum, or in the prices paid by consumers of petroleum products such as gasoline. These costs include (1) higher prices for petroleum products resulting from the effect of U.S. oil import demand on the world oil price; (2) the risk of disruptions to the U.S. economy caused by sudden reductions in the supply of imported oil to the U.S.; and (3) expenses for maintaining a U.S. military presence to secure imported oil supplies from unstable regions, and for maintaining the strategic petroleum reserve (SPR) to cushion against resulting price increases.[347]

Higher U.S. consumption and imports of crude oil or refined petroleum products can raise the magnitude of these external economic costs, thus increasing the true economic cost of supplying transportation fuels above the resource costs of producing them. Conversely, *reducing* fuel consumption by requiring motor vehicles to achieve higher fuel economy will lower U.S. consumption and imports of crude petroleum and refined fuels, thus lowering the values of these external costs. Any reduction in their value that results from requiring improved vehicle fuel economy represents an additional economic benefit of raising CAFE standards, over and above the economic value of saving fuel itself.

Increased U.S. petroleum consumption can impose higher costs on all purchasers of petroleum products, because the U.S. is a sufficiently large purchaser of foreign oil supplies that changes in U.S. demand can affect the world petroleum price. The effect of U.S. petroleum demand on world oil prices is determined by the degree of OPEC monopoly power over global oil supplies, and the degree of monopsony power over world oil demand that the U.S. exercises. The importance of these two factors means that increases in domestic demand for petroleum products that are met through higher oil imports can cause the price of oil in the world market to rise,

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[347] *See, e.g.,* Bohi, Douglas R. and W. David Montgomery (1982). Oil Prices, Energy Security, and Import Policy Washington, DC: Resources for the Future, Johns Hopkins University Press; Bohi, D. R., and M. A. Toman (1993). "Energy and Security: Externalities and Policies," Energy Policy 21:1093-1109; and Toman, M. A. (1993) (Docket NHTSA-2009-0062-24). "The Economics of Energy Security: Theory, Evidence, Policy," in A. V. Kneese and J. L. Sweeney, eds. (1993) (Docket NHTSA-2009-0062-23). Handbook of Natural Resource and Energy Economics, Vol. III. Amsterdam: North-Holland, pp. 1167-1218.

which imposes economic costs on all other purchasers in the global petroleum market in excess of the higher prices paid by U.S. consumers.[348] Conversely, reducing U.S. oil imports can lower the world petroleum price, and thus generate benefits to other oil purchasers by reducing these "monopsony costs."

Although the degree of current OPEC monopoly power is subject to considerable debate, the consensus appears to be that OPEC remains able to exercise some degree of control over the response of world oil supplies to variation in world oil prices, so that the world oil market does not behave competitively.[349] The extent of U.S. monopsony power is determined by a complex set of factors including the relative importance of U.S. imports in the world oil market, and the sensitivity of petroleum supply and demand to its world price among other participants in the international oil market. Most evidence appears to suggest that variation in U.S. demand for imported petroleum continues to exert some influence on world oil prices, although this influence appears to be limited.[350]

In analyzing benefits from its actions to increase light truck CAFE standards for model years 2005-07 and 2008-11, NHTSA relied on a 1997 study by Oak Ridge National Laboratories (ORNL) to estimate the value of reduced economic externalities from petroleum consumption and imports.[351] More recently, ORNL updated its estimates of the value of these externalities, using the analytic framework developed in its original 1997 study in conjunction with recent estimates of the variables and parameters that determine their value. [352] These include world oil prices, current and anticipated future levels of OPEC petroleum production, U.S. oil import levels, the estimated responsiveness of regional oil supplies and demands to prices in different regions of the world, and the likelihood of oil supply disruptions. ORNL's prepared its updated estimates of oil import externalities were for use by EPA in evaluating the benefits of reductions in U.S. oil consumption and imports expected to result from its Renewable Fuel Standard Rule of 2007 (RFS)[353].

The updated ORNL study was subjected to a detailed peer review, and its estimates of the value of oil import externalities were subsequently revised to reflect their comments and

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[348] For example, if the U.S. imports 10 million barrels of petroleum per day at a world oil price of $80 per barrel, its total daily import bill is $800 million. If increasing imports to 11 million barrels per day causes the world oil price to rise to $81 per barrel, the daily U.S. import bill rises to $891 million. The resulting increase of $91 million per day ($891 million minus $800 million) is attributable to increasing daily imports by only 1 million barrels. This means that the incremental cost of importing each additional barrel is $91, or $10 more than the newly-increased world price of $81 per barrel. This additional $10 per barrel represents a cost imposed on all other purchasers in the global petroleum market by U.S. buyers, in excess of the price they pay to obtain those additional imports.

[349] For a summary see Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, *Oil Imports: An Assessment of Benefits and Costs*, ORNL-6851, Oak Ridge National Laboratory, November 1, 1997, at 17. *Available at* http://pzl1.ed.ornl.gov/ORNL6851.pdf (last accessed March 17, 2010).

[350] *Id.*, at 18-19.

[351] Leiby, Paul N., Donald W. Jones, T. Randall Curlee, and Russell Lee, *Oil Imports: An Assessment of Benefits and Costs*, ORNL-6851, Oak Ridge National Laboratory, November 1, 1997. *Available at* http://pzl1.ed.ornl.gov/ORNL6851.pdf (last accessed March 17, 2010).

[352] Leiby, Paul N. "Estimating the Energy Security Benefits of Reduced U.S. Oil Imports," Oak Ridge National Laboratory, ORNL/TM-2007/028, Revised July 23, 2007. *Available at* http://pzl1.ed.ornl.gov/energysecurity.html (click on link below "Oil Imports Costs and Benefits") (last accessed March 15, 2010).

[353] Federal Register Vol.72, #83, May 1, 2007 pp.23,900-24,014

recommendations.[354] Specifically, reviewers recommended that ORNL increase its estimates of the sensitivity of oil supply by non-OPEC producers and oil demand by nations other than the U.S. to changes in the world oil price, as well as reduce its estimate of the sensitivity of U.S. gross domestic product (GDP) to potential sudden increases in world oil prices. These revisions significantly changed ORNL's estimates of some components of the external costs of U.S. petroleum imports.

At the request of EPA, ORNL further revised its 2008 estimates of external costs from U.S. oil imports to reflect recent changes in the outlook for world petroleum prices and continuing changes in the structure and characteristics of global petroleum supply and demand. These most recent revisions increase ORNL's estimates of the monopsony cost associated with U.S. oil imports to $4.67 to $23.40 per barrel, with a most likely estimate of $12.91 per barrel of petroleum imported into the U.S. (expressed in 2009 dollars).[355] These estimates imply that each gallon of fuel saved as a result of adopting higher CAFE standards that is reflected in lower U.S. imports of crude petroleum (or, presumably, refined products) will reduce the monopsony costs imposed by U.S. oil imports by $0.112 to $0.557 per gallon, with the actual value most likely to be $0.308 per gallon saved (again in 2009 dollars).

These figures represent the reduced value of payments from U.S. oil purchasers to foreign oil suppliers that results when lower U.S. oil demand reduces the world price of petroleum, beyond the savings from reduced purchases of petroleum itself.[356] Consistency with NHTSA's use of estimates of the *global* benefits from reducing emissions of CO_2 and other greenhouse gases in this analysis, however, requires the use of a global perspective for assessing their net value. From this perspective, reducing these payments simply results in a transfer of resources from foreign oil suppliers to U.S. purchasers (or more properly, in a savings in the value of resources previously transferred from U.S. purchasers to foreign producers), and provides no real savings in resources to the global economy. Thus NHTSA's analysis of the benefits from adopting higher CAFE standards for MY 2017-2025 cars and light trucks *excludes* the reduced value of monopsony payments by U.S. oil consumers that might result from lower fuel consumption by these vehicles.

The second component of external economic costs imposed by U.S. petroleum imports arises partly because an increase in oil prices triggered by a disruption in the supply of imported oil reduces the level of output that the U.S. economy can produce. The reduction in potential U.S. economic output depends on the extent and duration of the increases in petroleum product prices that result from a disruption in the supply of imported oil, as well as on whether and how rapidly these prices return to pre-disruption levels. Even if prices for imported oil return completely to their original levels, however, economic output will be at least temporarily reduced from the level that would have been possible without a disruption in oil supplies.

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[354] *Peer Review Report Summary: Estimating the Energy Security Benefits of Reduced U.S. Oil Imports*, ICF, Inc., September 2007. Docket NHTSA-2009-0059-0160

[355] ORNL estimates have been converted to 2009$ using the GDP implicit price deflator.

[356] The reduction in payments from U.S. oil purchasers to domestic petroleum producers is not included as a benefit, since it represents a transfer that occurs entirely within the U.S. economy.

Because supply disruptions and resulting price increases tend to occur suddenly rather than gradually, they can also impose costs on businesses and households for adjusting their use of petroleum products more rapidly than if the same price increase had occurred gradually over time. These adjustments impose costs because they temporarily reduce economic output even below the level that would ultimately be reached once the U.S. economy completely adapted to higher petroleum prices. The additional costs to businesses and households reflect their inability to adjust prices, output levels, and their use of energy and other resources 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 these disruption costs must be adjusted by the probability that the supply of imported oil to the U.S. will actually be disrupted. The "expected value" of these costs – the product of the probability that an oil import disruption will occur and the costs of reduced economic output and abrupt adjustment to sharply higher petroleum prices – is the appropriate measure of their magnitude. Any reduction in the expected value of these costs resulting from a measure that lowers U.S. oil imports represents an additional benefit to the U.S. economy *beyond* the direct value of savings from reduced purchases of petroleum products.

While the vulnerability of the U.S. economy to oil price shocks is widely believed to depend on *total* petroleum consumption rather than on the level of oil imports, variation in imports is still likely to have some effect on the magnitude of price increases resulting from a disruption of import supply. In addition, changing the quantity of petroleum imported into the U.S. may also affect the probability that such a disruption will occur. If either the size of the likely price increase or the probability that U.S. oil supplies will be disrupted is affected by oil imports, the expected value of the economic costs resulting from potential supply disruptions will also depend on the level of imports.

Businesses and households use a variety of market mechanisms, including oil futures markets, energy conservation measures, and technologies that permit rapid fuel switching to "insure" against higher petroleum prices and reduce their costs for adjusting to sudden price increases. While the availability of these market mechanisms has probably reduced the potential costs of disruptions to the supply of imported oil over time, consumers of petroleum products are unlikely to take account of costs they impose on others, so these costs are probably not fully reflected in the price of imported oil. Thus changes in oil import levels probably continue to affect the expected cost to the U.S. economy from potential oil supply disruptions, although this component of oil import costs is likely to be significantly smaller than estimated by studies conducted in the wake of the oil supply disruptions that occurred during the 1970s.

ORNL's most recently updated and revised estimates of the increase in the expected costs associated with oil supply disruptions to the U.S. and the resulting rapid increase in prices for petroleum products amount to $3.41 to $11.68 per barrel of imported oil, with a most likely estimate of $7.33 per barrel of imports (all figures are in 2009 dollars). According to these estimates, each gallon of fuel saved that results in a reduction in U.S. petroleum imports (either crude petroleum or refined fuel) will reduce the expected costs of oil supply disruptions to the U.S. economy by $0.081 to $0.278, with the actual value most likely to be $0.174 per gallon (again in 2009 dollars). Unlike the reduction in monopsony payments that results from lower

U.S. petroleum imports, however, the reduction in these expected disruption costs represents a real savings in resources, and thus contributes economic benefits in addition to the savings in resource costs for fuel production that would result from increasing fuel economy. NHTSA employs these values in its evaluation of the economic benefits from adopting higher CAFE standards for MY 2017-2025 cars and light trucks.

The third component of the external economic costs of importing oil into the U.S. includes government outlays for maintaining a military presence to secure the supply of oil imports from potentially unstable regions of the world and protect against their interruption. Some analysts also include outlays for maintaining the U.S. Strategic Petroleum Reserve (SPR) as an additional cost of U.S. dependence on oil imports, since the SPR is intended to cushion the U.S. economy against the consequences of disruption in the supply of imported oil.

NHTSA currently believes that while costs for U.S. military security may vary over time in response to long-term changes in the actual level of oil imports into the U.S., these costs are unlikely to decline in response to any reduction in U.S. oil imports resulting from raising future CAFE standards for light-duty vehicles. U.S. military activities in regions that represent vital sources of oil imports also serve a broader range of security and foreign policy objectives than simply protecting oil supplies, and as a consequence are unlikely to vary significantly in response to changes in the level of oil imports prompted by higher standards.

Neither the Congress nor the Executive Branch has ever attempted to calibrate U.S. military expenditures, force levels, or deployments to any oil market variable, or to some calculation of the projected economic consequences of hostilities in the Persian Gulf. Instead, changes in U.S. force levels, deployments, and thus military spending in that region have been largely governed by political events, emerging threats, and other military and political considerations, rather than by shifts in U.S. oil consumption or imports. NHTSA thus concludes that the levels of U.S. military activity and expenditures are likely to remain unaffected by even relatively large changes in light duty vehicle fuel consumption. As a consequence, the agency's analysis of alternative CAFE standards for MYs 2017-2025 does not include savings in budgetary outlays to support U.S. military activities among the benefits of higher fuel economy and the resulting fuel savings.

Nevertheless, the agency conducted a sensitivity analysis of the potential effect of assuming that some reduction in military spending would result from fuel savings and reduced petroleum imports in order to investigate its impacts on the standards and fuel savings. Assuming that the preceding estimate of total U.S. military costs for securing Persian Gulf oil supplies is correct, the estimated savings would range from \$0.03 to \$0.17 (in 2009 dollars)[357] for each gallon of fuel savings resulting in lower U.S. imports of petroleum from the Persian Gulf.[358] If the Persian Gulf region is assumed to be the marginal source of supply for U.S. imports of crude petroleum and refined products, then each gallon of fuel saved might reduce U.S. military outlays by some amount within the above range. NHTSA selected a value of \$0.12 per gallon for its sensitivity

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[357] Values converted to 2009 dollars using GDP implicit price deflator.

[358] Mark A. Delucchi and James J. Murphy. "US Military Expenditures to Protect the Use of Persian Gulf Oil for Motor Vehicles." Energy Policy, Volume 36, Issue 6, June 2008, pages 2253-2264. *Available at* http://www.sciencedirect.com/science/article/pii/S0301421508001262 (last accessed November 14, 2011)

analysis involving the military security component, slightly above the midpoint of the range identified by Delucchi and Murphy.

Similarly, while the optimal size of the SPR from the standpoint of its potential influence on domestic oil prices during a supply disruption may be related to the level of U.S. oil consumption and imports, its actual size has not appeared to vary in response to recent changes in oil imports. Thus while the budgetary costs for maintaining the Reserve are similar to other external costs in that they are not likely to be reflected in the market price for imported oil, these costs do not appear to have varied in response to changes in oil import levels. As a result, the agency's analysis of benefits from alternative CAFE standards for MY 2017-2025 does not include cost savings from maintaining a smaller SPR among the external benefits of reducing gasoline consumption and petroleum imports by means of tightening future CAFE standards. This view concurs with that of the recent ORNL study of economic costs from U.S. oil imports, which concludes that savings in government outlays for these purposes are unlikely to result from reductions in consumption of petroleum products and oil imports on the scale of those resulting from higher CAFE standards.

The Impact of Fuel Savings on U.S. Petroleum Imports

Based on a detailed analysis of differences in fuel consumption, petroleum imports, and imports of refined petroleum products among the Reference Case, High Economic Growth, and Low Economic Growth Scenarios presented in the Energy Information Administration's Annual Energy Outlook 2009, NHTSA estimates that approximately 50 percent of the reduction in fuel consumption resulting from adopting higher CAFE standards is likely to be reflected in reduced U.S. imports of refined fuel, while the remaining 50 percent would be expected to be reflected in reduced domestic fuel refining.[359] 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.[360] Thus on balance, each gallon of fuel saved as a consequence of higher CAFE standards is anticipated to reduce total U.S. imports of crude petroleum or refined fuel by 0.95 gallons.[361]

The Economic Value of Reducing CO_2 Emissions

NHTSA has taken the economic benefits of reducing CO_2 emission into account in this rulemaking, both in developing alternative CAFE standards and in assessing the economic benefits of each alternative that was considered. Since direct estimates of the economic benefits from reducing CO_2 or other GHG emissions are generally not reported in published literature on the impacts of climate change, these benefits are typically assumed to be the "mirror image" of the estimated incremental *costs* resulting from an increase in those emissions. Thus, the benefits

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[359] Differences between forecast annual U.S. imports of crude petroleum and refined products among these three scenarios range from 24-89% of differences in projected annual gasoline and diesel fuel consumption in the U.S. These differences average 49% over the forecast period spanned by AEO 2009.

[360] Differences between forecast annual U.S. imports of crude petroleum among these three scenarios range from 67-97% of differences in total U.S. refining of crude petroleum, and average 85% over the forecast period spanned by AEO 2009.

[361] This figure is calculated as 0.50 + 0.50*0.9 = 0.50 + 0.45 = 0.95.

from reducing CO_2 emissions are usually measured by the savings in estimated economic damages that an equivalent *increase* in emissions would otherwise have caused.

The “social cost of carbon” (SCC) is intended to be a monetary measure of the incremental damage resulting from increased carbon dioxide (CO_2) emissions, including losses in agricultural productivity, the economic damages caused by adverse effects on human health, property losses and damages resulting from sea level rise, and changes in the economic value of ecosystem services. The SCC is usually expressed in dollars per additional metric ton of CO_2 emissions occurring during a specified year, and is higher for more distant future years because the damages caused by an additional ton of emissions increase with larger existing concentrations of CO_2 in the earth’s atmosphere. 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 estimated SCC appropriate for that year, which is used to represent the value of eliminating each ton of CO_2 emissions, to determine the total economic benefit from reduced emissions during that year. These benefits are then discounted to their present value as usual, using a discount rate that is consistent with that used to develop the estimate of the SCC itself.

For this final rule, NHTSA has relied on estimates of the SCC developed by a federal interagency working group convened for the specific purpose of developing new estimates to be used by U.S. federal agencies in regulatory evaluations. Under Executive Order 12866, federal agencies are required, to the extent permitted by law, “to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.” The group’s purpose in developing new estimates of the SCC was to allow federal agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or “marginal,” impacts on cumulative global emissions, as most federal regulatory actions can be expected to have.

The interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process included the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group developed its estimates of the SCC estimates while clearly acknowledging the many uncertainties involved, and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literature. In this way, key uncertainties and model differences transparently and consistently can inform the range of SCC estimates used in the rulemaking process.

The group ultimately selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, using discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent the possibility of higher-than-expected impacts from temperature change that lie further out in the tails of the distribution of SCC estimates. Table VIII-15 summarizes the interagency group's estimates of the SCC during various future years. The SCC estimates reported in the table assume that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions.

Table VIII-15
Social Cost of CO_2 Emissions, 2010 – 2050 (2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Source	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

As Table VIII-15 shows the four SCC estimates selected by the interagency group for use in regulatory analyses are $5, $21, $35, and $65 (in 2007 dollars) for emissions occurring in the year 2010. The first three estimates are based on the average SCC across models and socio-economic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, the group elected to use the SCC value for the 95th percentile at a 3 percent discount rate.

Table VIII-15 cites values in 2007 dollars to maintain consistency with the final CAFE rulemaking for MYs 2012-2016. However, the agency updated these values to 2009 dollars for the current rulemaking. Expressed in 2009 dollars, the four SCC estimates selected for this regulatory analysis are (rounded to the nearest dollar): $5, $22, $36, $67.

The central value identified by the interagency group is the average SCC across models at the 3 percent discount rate, or $21 per metric ton for the year 2010, expressed in 2007 dollars ($22 in 2009 dollars). 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 also shows, the SCC estimates also rise over time; for example, the central value increases to $24 per ton of CO_2 in 2015 and $26 per ton of CO_2 in 2020.

The interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, the group have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. U.S. federal agencies will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

Details of the process used by the interagency group to develop its SCC estimates, complete results including year-by-year estimates of each of the four values, and a thorough discussion of their intended use and limitations is provided in the document *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, Interagency Working Group on Social Cost of Carbon, United States Government, February 2010.[362]

Benefits from Reducing Emissions of Criteria Air Pollutants

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 (PM2.5), and sulfur dioxide (SO_2). 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 from higher fuel economy will increase emissions of these pollutants. Thus the net effect of stricter CAFE standards on total emissions of each criteria pollutant depends on the relative magnitudes of reduced emissions in fuel refining and distribution, and increases in emissions from vehicle use. Because the relationship between emission rates (emissions per gallon refined of fuel or mile driven) in fuel refining and vehicle use is different for each criteria pollutant, the net effect of fuel savings from increased CAFE standards on total emissions of each pollutant is likely to differ.

NHTSA estimates the increase 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 as well as between gasoline and diesel vehicles, and both their values for new vehicles and the rates at which they increase with age and accumulated mileage can vary among model years. With the exception of SO_2, NHTSA calculated the increase in emissions of these criteria pollutants from added car and light truck use by multiplying the estimated increases in their vehicles' 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.

These emission rates were developed by U.S. EPA using its recently-developed Motor Vehicle Emission Simulator (MOVES 2010). The MOVES model assumes that the per-mile rates at which these pollutants are emitted are determined by EPA regulations and the effectiveness of catalytic after-treatment of engine exhaust emissions, and are thus unaffected by changes in car and light truck fuel economy. As a consequence, the effects of required increases in fuel economy 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 for use in NHTSA's calculations, MOVES was run for the year 2050, and was programmed to report aggregate emissions from vehicle start and running exhaust. EPA analysts selected

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[362] This document is available at http://www2.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/sem_finalrule_appendix15a.pdf (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131.

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.[363] 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 average distance traveled in order to produce per-mile emission factors for each pollutant. The resulting emission rates represent average values across the nation, and incorporate typical temperature variations 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.[364]

Emission rates for the criteria pollutant SO_2 were calculated by NHTSA using average fuel sulfur content estimates supplied by EPA, together with the 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.[365] Total SO_2 emissions under each alternative CAFE standard were calculated by applying the resulting emission rates directly to annual gasoline and diesel fuel use by cars and light trucks that is projected to occur under that alternative. As with other impacts, the *changes* in emissions of criteria air pollutants resulting from alternative increases in CAFE standards for MY 2017-2025 cars and light trucks were calculated as the difference between emissions under each alternative that would increase CAFE standards and emissions under the baseline alternative, which would extend the MY 2016 CAFE and EPA GHG emissions standards to apply to future model years.

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. NHTSA's analysis assumes 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,

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[363] Because all light-duty emission rates in MOVES 2010 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.

[364] 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.

[365] 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.

reduced domestic fuel refining using domestically-produced crude oil is assumed to reduce emissions during all four phases of fuel production and distribution.[366]

NHTSA estimated the reductions in criteria pollutant emissions from producing and distributing fuel that would occur with alternative CAFE standards using emission rates obtained by EPA from Argonne National Laboratories' Greenhouse Gases and Regulated Emissions in Transportation (GREET) model.[367] 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.[368] EPA modified 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. 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 the agency's estimates of fuel consumption under each alternative CAFE standard 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 CAFE standards on changes in domestic emissions of each criteria pollutant.

Finally, 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, and the reductions in emissions anticipated to result from lower domestic fuel refining and distribution.[369] As indicated previously, the effect of adopting higher CAFE 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. Although these net changes vary significantly among individual criteria pollutants, the agency projects that on balance, adopting higher CAFE standards would reduce emissions of all criteria air pollutants except carbon monoxide (CO).

The net changes in domestic emissions of fine particulates (PM2.5) and its chemical precursors (such as NOx, SOx, and VOCs) are converted to economic values using estimates of the reductions in health damage costs per ton of emissions of each pollutant that is avoided, which were developed and recently revised by EPA. These savings represent the estimated reductions

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[366] 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.

[367] Argonne National Laboratories, *The Greenhouse Gas and Regulated Emissions from Transportation (GREET) Model, available at* http://greet.es.anl.gov/ (last accessed November 14, 2011).

[368] 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.

[369] All emissions from increased vehicle use are assumed to occur within the U.S., since CAFE standards would apply only to vehicles produced for sale in the U.S.

in the value of damages to human health resulting from lower atmospheric concentrations and population exposure to air pollution that occur when emissions of each pollutant that contributes to atmospheric PM2.5 concentrations are reduced. The value of reductions in the risk of premature death due to exposure to fine particulate pollution (PM2.5) account for a majority of EPA's estimated values of reducing PM2.5 related emissions, although the value of avoiding other health impacts related to PM2.5 exposure is also included in these estimates. These values do not include a number of unquantified benefits, such as reduction in the welfare and environmental impacts of PM2.5 pollution, or reductions in health and welfare impacts related to other criteria pollutants (ozone, NO2, and SO2) and air toxics. EPA estimates different PM-related per-ton values for reducing emissions from vehicle use than for reductions in emissions of that occur during fuel production and distribution. NHTSA applies these separate values to its estimates of changes in emissions from vehicle use and fuel production and distribution to determine the net change in total economic damages from emissions of these pollutants.

EPA projects that the per-ton values for reducing emissions of criteria pollutants from both mobile sources (including motor vehicles) and stationary sources such as fuel refineries and storage facilities will increase over time. 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, as well as future population growth, which increases population exposure to future levels of air pollution.

D. Added Costs from Congestion, Crashes, and Noise

While it provides some benefits to drivers, increased vehicle use associated with the fuel economy rebound effect can also contribute to increased traffic congestion, motor vehicle crashes, and highway noise. Additional vehicle use can contribute to traffic congestion and delays by increasing recurring congestion on heavily-traveled roadways during peak travel periods, depending on how the additional travel is distributed over the day and on where it occurs. By increasing the number of crashes and disabled vehicles, added driving can also increase the delays that often result from these incidents, although the extent to which it actually does so again depends on when and where the added travel occurs.

In either case, added delays impose higher costs on drivers and other vehicle occupants in the form of increased travel time and operating expenses, and these should be considered as an additional economic cost associated with the rebound effect. Because drivers do not take these added costs into account in deciding when to make trips or where they travel, they must be accounted for separately as a cost of the added driving associated with the rebound effect.

Increased passenger car and light truck use due to the rebound effect may also increase the costs associated with traffic crashes. Drivers presumably take account of the potential costs they (and the other occupants of their vehicles) face from the possibility of being involved in a crash 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 crashes occur, so any increase in these "external" crash costs must be considered as another cost of additional rebound-effect driving.

Like increased delay costs, any increase in these external crash costs caused by added driving is likely to depend on the traffic conditions under which it takes place, since crashes are more frequent in heavier traffic, but their severity may be reduced by the slower speeds at which heavier traffic typically moves. Thus estimates of the increase in external crash costs from the rebound effect also need to account for when and where the added driving occurs.

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 none of these effects are likely 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 estimating its value, the added inconvenience and irritation caused by increased traffic noise imposes some economic costs on those it affects, and these added costs are unlikely to be taken into account by drivers of the vehicles that cause it. Thus any increase in noise costs resulting from added vehicle use must be included together with other increases in external costs of additional rebound-effect driving.

NHTSA's analysis uses estimates of the congestion, crash, and noise costs caused by increased travel in automobiles, pickup trucks, and vans developed by the Federal Highway Administration.[370] These estimates are intended to measure the *increases* in external costs – that is, the "marginal" external costs – from added congestion, property damages and injuries in traffic crashes, and noise levels caused by additional usage of cars and light trucks that are borne by persons other than their drivers. FHWA's "Middle" estimates for congestion, crash, and noise costs imposed by passenger cars are 5.6 cents, 2.4 cents and 0.1 cents per additional vehicle mile when expressed in 2009 dollars.[371] For pickup trucks and vans, FHWA's estimates correspond to 4.9 cents, 2.7 cents, and 0.1 cents per additional vehicle-mile.

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 crash costs for increased light-duty vehicle use in the U.S. to be 4.0 and 3.5 cents per vehicle-mile when converted to 2009 dollars.[372] These estimates incorporate careful adjustments of congestion and crash costs that are intended to reflect the traffic conditions under which additional driving is likely to take place, as well as its likely effects on both the frequency and severity of motor vehicle crashes.

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[370] These estimates were developed by FHWA for use in its 1997 *Federal Highway Cost Allocation Study*, available at http://www.fhwa.dot.gov/policy/hcas/final/index.htm. (last accessed on March 15, 2010)

[371] Federal Highway Administration, 1997 *Federal Highway Cost Allocation Study*, Tables V-22, V-23, and V-24, http://www.fhwa.dot.gov/policy/hcas/final/index.htm (last accessed on November 14, 2011). The higher congestion cost for automobiles than for light trucks reflects the larger fraction of auto than of light truck use that occurs within congested urban areas.

[372] 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, March 2002, pp. 19 and Table 1, http://www.rff.org/rff/Documents/RFF-DP-02-12.pdf. (last accessed on November 14, 2011) or Docket No. NHTSA-2010-0131.

FHWA's estimates of added costs for congestion, crashes , and noise are multiplied by the estimated increases in passenger car and light truck use due during each year of the affected model years' lifetimes to yield the estimated increases in congestion, crash, and noise externality costs. The resulting yearly estimates are then summed to obtain their lifetime values. The value of these increased costs varies among model years and the alternative increases in CAFE standards considered in this analysis, because the increases in vehicle use depend on the improvements in fuel economy that would result in specific model years under each alternative.

E. The Discount Rate

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 today's perspective – for each year they are deferred into the future. In evaluating the benefits from alternative increases in CAFE standards for MY 2017-2025 passenger cars and light trucks, NHTSA separately estimated benefits at both 3% and 7% discount rates per year. Inclusion of the 7% discount rate in this rulemaking's central analysis is a departure from the previous rulemaking, in which the 7% discount rate was treated as a separate sensitivity analysis.

The primary reason that NHTSA selected 3 percent as the appropriate rate for discounting future benefits from increased CAFE standards is that most or all of vehicle manufacturers' costs for complying with higher CAFE 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, CAFE regulation 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 social rate of time preference.[373] Also of note is that 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 social rate of time preference.[374]

One important exception to the 3 percent discount rate matches the rates used to discount benefits from reducing CO_2 emissions from the years in which reduced emissions occur, which span the lifetimes of MY 2017-2025 cars and light trucks, to their present values. In order to ensure consistency in the derivation and use of the interagency group's estimates of the unit values of reducing CO_2 emissions, the benefits from reducing those emissions during each future year are discounted using the *same* "intergenerational" discount rates that were used to derive each of the alternative unit values of reducing CO_2 emissions. As Table VIII-15 above shows, these rates are 5 percent for the interagency group's lowest estimate of the SCC, 3 percent for its central and highest estimates, and 2.5 percent for the estimate lying between the group's central and highest estimates.

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[373] *Id.*

[374] Office of Management and Budget, Circular A-4, "Regulatory Analysis," September 17, 2003, 33. *Available at* http://www.whitehouse.gov/sites/default/files/omb/assets/regulatory_matters_pdf/a-4.pdf (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131.

Because there is some uncertainty about the extent to which vehicle manufacturers will be able to recover their costs for complying with higher CAFE standards by increasing vehicle sales prices, however, NHTSA elected to include a 7 percent discount rate in the central analysis, whereas historically variation of the discount rate has been reserved for sensitivity analyses. 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.[375]

All costs and benefits are discounted to the time that the vehicle is purchased or the model year. Thus, from a consumer perspective the costs occur when the vehicle is purchased and the fuel savings occur throughout the lifetime of the vehicle and are discounted back to the time the vehicle was purchased. From the manufacturers' perspective, the costs are assigned to the model year that the countermeasure is added to the vehicle. Thus, all costs and benefits are assumed to either occur in the model year or are discounted back to the model year for which the vehicle is produced. When we accumulate MY 2017-2025 total costs or benefits, we are simply adding together the present discounted values for each model year. We do not further discount those model year values to any set year (e.g. we do not discount all the values to 2017 or to 2012). All costs and benefits are in 2009 dollars.

F. Summary of Values used to Estimate Benefits

Table VIII-16 summarizes the economic values used to estimate benefits.

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[375] *Id.*

Table VIII-16
Economic Values Used for Benefits Computations (2009 dollars)

Fuel Economy Rebound Effect	10%
"Gap" between test and on-road MPG	20%
Value of refueling time per ($ per vehicle-hour)	$ 21.43
Average Percentage of Tank Refilled During Refueling	65%
Annual growth in average vehicle use (through 2030)	1.1%
Annual growth in average vehicle use (beyond 2030)	0.50%
Fuel Prices (2017-2060 average, $/gallon)	
Retail gasoline price	$3.76
Pre-tax gasoline price	$3.42
Economic Benefits from Reducing Oil Imports ($/gallon)	
"Monopsony" Component	$ 0.00
Price Shock Component	$ 0.17
Military Security Component	$ 0.00
Total Economic Costs ($/gallon)	$ 0.17
Emission Damage Costs (weighted, $/ton or $/metric ton)	
Carbon monoxide	$ 0
Volatile organic compounds (VOC)	$ 1,600
Nitrogen oxides (NOx)	$ 6,600
Particulate matter (PM$_{2.5}$)	$ 300,000
Sulfur dioxide (SO$_2$)	$ 39,000
Carbon dioxide (CO$_2$) emissions in 2010	$ 22
Annual Increase in CO$_2$ Damage Cost	Variable
External Costs from Additional Automobile Use ($/vehicle-mile)	
Congestion	$ 0.056
Accidents	$ 0.024
Noise	$ 0.001
Total External Costs	$ 0.080
External Costs from Additional Light Truck Use ($/vehicle-mile)	
Congestion	$0.049
Accidents	$0.027
Noise	$0.001
Total External Costs	$0.077
Discount Rates Applied to Future Benefits[376]	3%, 7%

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[376] Future benefits from reducing CO$_2$ emissions are discounted using the *same* "intergenerational" discount rates that were used to derive each of the alternative SCC estimates used to value reductions in those emissions. As Table VIII-12 above shows, these rates are 5 percent for the interagency group's lowest estimate of the SCC, 3 percent for its central and highest estimates, and 2.5 percent for the estimate lying between the group's central and highest estimates.

G. Benefits Estimates

Benefits were calculated separately for passenger cars and light trucks under each alternative CAFE requirement for each model year covered by this proposal. In Tables VIII-17 and VIII-18, the societal impacts for passenger car and light truck CAFE standards under the preferred alternative is shown for model years 2017-2025. These tables include undiscounted values as well as their net present values discounted to the given model year at 3 percent and 7 percent. Positive values in these tables reflect net reductions in fuel consumption or emissions and their resulting economic impacts, which represent benefits from the proposal, while negative values represent increasing emissions, congestion, noise or crash severity and their added costs. The net social benefit from these societal impacts is shown on the Total line in each table.

The preferred alternative for passenger cars would save 94.6 billion gallons of fuel and prevent 999 million metric tons of CO_2 emissions over the lifetime of the passenger cars sold during those model years, compared to the fuel savings and emissions reductions that would occur if the standards remained at the adjusted baseline for MYs 2017-2025. The preferred alternative for light trucks would save 64.2 billion gallons of fuel and prevent 698.4 million metric tons of CO_2 emissions over the lifetime of the light trucks sold during those model years, compared to the fuel savings and emissions reductions that would occur if the standards remained at the adjusted baseline for MYs 2017-2025.

The sum of the net present values of societal benefits resulting from the implementation of the preferred alternative for passenger cars and light trucks is $477 billion[377] over the lifetime of the MY 2017-25 fleet. This estimate of societal benefits includes direct impacts from lower fuel consumption as well as externalities, and also reflects offsetting societal costs resulting from the rebound effect. This estimate does not include technology costs. Fuel savings account for 87.4 percent and CO_2 emissions account for 9.6 percent of net societal benefits.

Tables VIII-19 and VIII-20 summarize the societal benefits for all alternatives for passenger cars and light trucks for each model year at the 3 percent and 7 percent discount rates, respectively (these Tables are analogous to Tables 13 and 14 in the Executive Summary, differing in that the Executive Summary presents these benefits at a combined level only). As would be expected, benefit levels parallel the increasing stringency of the various alternatives that were examined. The TC=TB scenario produces benefits that exceed the other alternatives because that methodology allows technologies that are cost effective to pay for some technologies that are not cost effective. Table VIII-21 summarizes the fuel savings, in gallons, from all alternatives for passenger cars and light trucks. Table VIII-21 presents fuel savings under both 3 percent and 7

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[377] The estimate of $468 billion is based on a 3% discount rate for valuing future impacts. In the case of a 7% discount rate, the sum of the net present are estimated at $388 billion.

percent discount rates; however, only the Max Net Benefits and Total Cost = Total Benefit alternatives produce differing results conditional on the discount rate.

Similar to Table VIII-21, Table VIII-22 presents the net change in electricity consumption, from all alternatives, for passenger cars and light trucks under both 3 and 7 percent discount rates. Note that under several of the alternatives, a net decrease in electricity consumption is projected for the passenger car fleet in certain model years ranging from MY 2017 to MY 2022. This result may seem counterintuitive due to trends that suggest increased use of HEV, PHEV, and EV technologies. This result can be explained by several factors. For certain alternatives, the stringency increases were gradual enough that the CAFE model did not add any EVs in earlier model years. Also, there were two EVs in the MY 2008 fleet, on which the baseline fleet was developed.[378] Application of the AC adjustment in the baseline scenario and the greater application of the AC adjustment in the alternative scenarios decreased vehicle energy consumption, therefore reducing electricity consumption in the various alternatives relative to the baseline.

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[378] BMW’s Mini-E and Tesla’s Roadster were both part of the MY 2008 fleet.

Table VIII-17
Lifetime Benefits for Preferred Alternative by Model Year
Passenger Cars
(2009 dollars, in millions)

MY 2017

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$6,582	$5,379	$4,290
Consumer Surplus from Additional Driving	$54	$44	$35
Refueling Time Value	$359	$296	$238
Petroleum Market Externalities	$351	$289	$233
Congestion Costs	($552)	($454)	($364)
Accident Costs	($245)	($201)	($161)
Noise Costs	($10)	($8)	($7)
Fatality Costs	($15)	($13)	($13)
CO2	$691	$559	$559
CO	$0	$0	$0
VOC	$8	$6	$5
NOX	$15	$13	$11
PM	$97	$82	$67
SOX	$100	$82	$66
Total	$7,435	$6,074	$4,960

MY 2018

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$12,515	$10,228	$8,159
Consumer Surplus from Additional Driving	$164	$134	$107
Refueling Time Value	$619	$510	$410
Petroleum Market Externalities	$662	$545	$438
Congestion Costs	($1,037)	($853)	($684)
Accident Costs	($461)	($379)	($303)
Noise Costs	($19)	($16)	($13)
Fatality Costs	($22)	($20)	($20)
CO2	$1,323	$1,069	$1,069
CO	$0	$0	$0
VOC	$15	$13	$11
NOX	$23	$20	$17
PM	$190	$159	$131
SOX	$188	$155	$124
Total	$14,160	$11,565	$9,446

MY 2019

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$20,084	$16,454	$13,152
Consumer Surplus from Additional Driving	$340	$278	$222
Refueling Time Value	$943	$778	$626
Petroleum Market Externalities	$1,055	$870	$700
Congestion Costs	($1,679)	($1,384)	($1,111)
Accident Costs	($740)	($609)	($489)
Noise Costs	($31)	($25)	($20)
Fatality Costs	($96)	($83)	($83)
CO2	$2,138	$1,733	$1,733
CO	$0	$0	$0
VOC	$26	$22	$18
NOX	$30	$27	$24
PM	$315	$264	$216
SOX	$299	$247	$199
Total	$22,685	$18,571	$15,186

MY 2020

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$27,503	$22,515	$17,991
Consumer Surplus from Additional Driving	$520	$426	$340
Refueling Time Value	$1,317	$1,084	$872
Petroleum Market Externalities	$1,432	$1,179	$949
Congestion Costs	($2,258)	($1,861)	($1,495)
Accident Costs	($1,002)	($825)	($662)
Noise Costs	($41)	($34)	($27)
Fatality Costs	($88)	($77)	($77)
CO2	$2,967	$2,402	$2,402
CO	$0	$0	$0
VOC	$35	$29	$24
NOX	$45	$39	$34
PM	$422	$353	$289
SOX	$401	$330	$266
Total	$31,251	$25,562	$20,906

MY 2021

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$33,388	$27,367	$21,895
Consumer Surplus from Additional Driving	$661	$542	$434
Refueling Time Value	$1,334	$1,098	$884
Petroleum Market Externalities	$1,739	$1,433	$1,154
Congestion Costs	($2,739)	($2,259)	($1,816)
Accident Costs	($1,212)	($999)	($802)
Noise Costs	($50)	($41)	($33)
Fatality Costs	($93)	($81)	($81)
CO2	$3,598	$2,915	$2,915
CO	$0	$0	$0
VOC	$52	$43	$35
NOX	$13	$14	$15
PM	$581	$482	$390
SOX	$483	$398	$321
Total	$37,755	$30,914	$25,309

MY 2022

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$38,681	$31,731	$25,409
Consumer Surplus from Additional Driving	$809	$665	$532
Refueling Time Value	$1,529	$1,259	$1,013
Petroleum Market Externalities	$1,999	$1,648	$1,327
Congestion Costs	($3,165)	($2,613)	($2,103)
Accident Costs	($1,400)	($1,155)	($929)
Noise Costs	($58)	($48)	($38)
Fatality Costs	($70)	($63)	($63)
CO2	$4,218	$3,421	$3,421
CO	$0	$0	$0
VOC	$61	$50	$40
NOX	$12	$15	$16
PM	$672	$557	$451
SOX	$558	$460	$370
Total	$43,845	$35,926	$29,447

MY 2023

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$46,509	$38,128	$30,525
Consumer Surplus from Additional Driving	$1,193	$978	$782
Refueling Time Value	$1,677	$1,382	$1,113
Petroleum Market Externalities	$2,405	$1,981	$1,594
Congestion Costs	($3,737)	($3,084)	($2,483)
Accident Costs	($1,662)	($1,370)	($1,102)
Noise Costs	($69)	($57)	($45)
Fatality Costs	($81)	($73)	($73)
CO2	$5,113	$4,144	$4,144
CO	$0	$0	$0
VOC	$79	$65	$52
NOX	$53	$45	$38
PM	$861	$701	$558
SOX	$525	$435	$352
Total	$52,868	$43,274	$35,453

MY 2024

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$54,610	$44,810	$35,909
Consumer Surplus from Additional Driving	$1,558	$1,279	$1,025
Refueling Time Value	$1,944	$1,603	$1,291
Petroleum Market Externalities	$2,806	$2,312	$1,862
Congestion Costs	($4,381)	($3,619)	($2,916)
Accident Costs	($1,946)	($1,606)	($1,293)
Noise Costs	($80)	($66)	($53)
Fatality Costs	($33)	($35)	($35)
CO2	$6,077	$4,930	$4,930
CO	$0	$0	$0
VOC	$92	$75	$60
NOX	$60	$51	$43
PM	$1,001	$816	$650
SOX	$618	$512	$414
Total	$62,326	$51,062	$41,887

MY 2025

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$64,160	$52,720	$42,302
Consumer Surplus from Additional Driving	$2,241	$1,845	$1,482
Refueling Time Value	$1,852	$1,526	$1,228
Petroleum Market Externalities	$3,334	$2,751	$2,217
Congestion Costs	($5,161)	($4,268)	($3,442)
Accident Costs	($2,283)	($1,886)	($1,520)
Noise Costs	($94)	($78)	($63)
Fatality Costs	($35)	($37)	($37)
CO2	$7,138	$5,801	$5,801
CO	$0	$0	$0
VOC	$122	$99	$79
NOX	$79	$65	$53
PM	$1,168	$944	$745
SOX	$437	$362	$292
Total	$72,957	$59,843	$49,137

MY 2017 – 2025 Combined

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$304,031	$249,332	$199,632
Consumer Surplus from Additional Driving	$7,541	$6,192	$4,958
Refueling Time Value	$11,575	$9,536	$7,675
Petroleum Market Externalities	$15,781	$13,008	$10,474
Congestion Costs	($24,709)	($20,396)	($16,414)
Accident Costs	($10,949)	($9,029)	($7,261)
Noise Costs	($452)	($373)	($300)
Fatality Costs	($534)	($481)	($481)
CO2	$33,262	$26,974	$26,974
CO	$0	$0	$0
VOC	$491	$403	$323
NOX	$331	$289	$250
PM	$5,306	$4,357	$3,498
SOX	$3,609	$2,981	$2,404
Total	$345,281	$282,792	$231,731

Table VIII-18
Lifetime Benefits for Preferred Alternative by Model Year
Light Trucks
(2009 dollars, in millions)

MY 2017

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$2,146	$1,699	$1,324
Consumer Surplus from Additional Driving	$16	$13	$10
Refueling Time Value	$86	$69	$54
Petroleum Market Externalities	$114	$91	$72
Congestion Costs	($125)	($100)	($79)
Accident Costs	($68)	($54)	($43)
Noise Costs	($3)	($2)	($2)
Fatality Costs	$39	$31	$31
CO2	$229	$179	$179
CO	$0	$0	$0
VOC	$2	$2	$2
NOX	$4	$4	$3
PM	$29	$24	$20
SOX	$32	$26	$20
Total	$2,501	$1,980	$1,591

MY 2018

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$6,404	$5,077	$3,959
Consumer Surplus from Additional Driving	$62	$50	$39
Refueling Time Value	$238	$191	$150
Petroleum Market Externalities	$335	$268	$211
Congestion Costs	($370)	($296)	($232)
Accident Costs	($200)	($160)	($126)
Noise Costs	($7)	($6)	($5)
Fatality Costs	$99	$79	$79
CO2	$691	$539	$539
CO	$0	$0	$0
VOC	$7	$6	$5
NOX	$13	$11	$9
PM	$86	$71	$58
SOX	$95	$76	$60
Total	$7,454	$5,906	$4,747

MY 2019

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$13,706	$10,874	$8,487
Consumer Surplus from Additional Driving	$173	$137	$107
Refueling Time Value	$478	$383	$302
Petroleum Market Externalities	$712	$570	$449
Congestion Costs	($794)	($636)	($500)
Accident Costs	($430)	($344)	($271)
Noise Costs	($16)	($13)	($10)
Fatality Costs	($3)	($2)	($2)
CO2	$1,496	$1,167	$1,167
CO	$0	$0	$0
VOC	$15	$13	$10
NOX	$27	$23	$20
PM	$182	$151	$123
SOX	$201	$161	$127
Total	$15,748	$12,484	$10,009

MY 2020

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$18,717	$14,862	$11,609
Consumer Surplus from Additional Driving	$250	$199	$156
Refueling Time Value	$669	$536	$422
Petroleum Market Externalities	$964	$772	$609
Congestion Costs	($1,077)	($864)	($679)
Accident Costs	($583)	($468)	($368)
Noise Costs	($22)	($17)	($14)
Fatality Costs	$114	$91	$91
CO2	$2,066	$1,613	$1,613
CO	$0	$0	$0
VOC	$21	$17	$14
NOX	$37	$32	$27
PM	$247	$205	$167
SOX	$273	$219	$172
Total	$21,676	$17,198	$13,820

MY 2021

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$26,528	$21,082	$16,482
Consumer Surplus from Additional Driving	$410	$327	$256
Refueling Time Value	$916	$734	$579
Petroleum Market Externalities	$1,358	$1,088	$858
Congestion Costs	($1,521)	($1,221)	($961)
Accident Costs	($823)	($661)	($520)
Noise Costs	($31)	($25)	($19)
Fatality Costs	$89	$71	$71
CO2	$2,959	$2,312	$2,312
CO	$0	$0	$0
VOC	$30	$25	$20
NOX	$48	$41	$35
PM	$356	$294	$240
SOX	$384	$308	$243
Total	$30,702	$24,377	$19,596

MY 2022

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$29,888	$23,773	$18,605
Consumer Surplus from Additional Driving	$499	$398	$312
Refueling Time Value	$1,025	$822	$648
Petroleum Market Externalities	$1,518	$1,217	$960
Congestion Costs	($1,711)	($1,374)	($1,083)
Accident Costs	($926)	($744)	($586)
Noise Costs	($35)	($28)	($22)
Fatality Costs	$129	$104	$104
CO2	$3,370	$2,636	$2,636
CO	$0	$0	$0
VOC	$34	$28	$23
NOX	$51	$44	$38
PM	$403	$332	$270
SOX	$430	$345	$272
Total	$34,675	$27,553	$22,176

MY 2023

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$32,862	$26,157	$20,486
Consumer Surplus from Additional Driving	$588	$470	$369
Refueling Time Value	$1,132	$908	$717
Petroleum Market Externalities	$1,658	$1,329	$1,049
Congestion Costs	($1,877)	($1,509)	($1,190)
Accident Costs	($1,016)	($817)	($644)
Noise Costs	($38)	($30)	($24)
Fatality Costs	$102	$82	$82
CO2	$3,751	$2,937	$2,937
CO	$0	$0	$0
VOC	$37	$30	$25
NOX	$56	$49	$42
PM	$438	$362	$294
SOX	$470	$377	$297
Total	$38,162	$30,344	$24,439

MY 2024

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$37,457	$29,837	$23,390
Consumer Surplus from Additional Driving	$735	$588	$462
Refueling Time Value	$1,315	$1,055	$833
Petroleum Market Externalities	$1,876	$1,505	$1,188
Congestion Costs	($2,128)	($1,712)	($1,352)
Accident Costs	($1,152)	($927)	($732)
Noise Costs	($43)	($35)	($27)
Fatality Costs	$55	$45	$45
CO2	$4,327	$3,391	$3,391
CO	$0	$0	$0
VOC	$42	$34	$28
NOX	$64	$56	$48
PM	$494	$408	$332
SOX	$531	$426	$336
Total	$43,574	$34,672	$27,942

MY 2025

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$42,362	$33,764	$26,487
Consumer Surplus from Additional Driving	$911	$730	$574
Refueling Time Value	$1,320	$1,059	$837
Petroleum Market Externalities	$2,116	$1,698	$1,341
Congestion Costs	($2,399)	($1,931)	($1,525)
Accident Costs	($1,299)	($1,046)	($826)
Noise Costs	($48)	($39)	($31)
Fatality Costs	($12)	($10)	($10)
CO2	$4,929	$3,866	$3,866
CO	$0	$0	$0
VOC	$52	$42	$34
NOX	$48	$45	$40
PM	$611	$500	$403
SOX	$601	$483	$381
Total	$49,193	$39,161	$31,571

MY 2017 – 2025 Combined

Societal Effect	Undiscounted Value	Sum of Present Discounted Values @ 3%	Sum of Present Discounted Values @ 7%
Lifetime Fuel Expenditures	$210,070	$167,125	$130,828
Consumer Surplus from Additional Driving	$3,644	$2,913	$2,284
Refueling Time Value	$7,180	$5,756	$4,542
Petroleum Market Externalities	$10,650	$8,539	$6,737
Congestion Costs	($12,002)	($9,644)	($7,601)
Accident Costs	($6,498)	($5,221)	($4,115)
Noise Costs	($242)	($195)	($154)
Fatality Costs	$613	$491	$491
CO2	$23,820	$18,640	$18,640
CO	$0	$0	$0
VOC	$240	$197	$160
NOX	$349	$305	$263
PM	$2,845	$2,348	$1,908
SOX	$3,018	$2,420	$1,909
Total	$243,685	$193,675	$155,891

Table VIII-19
Present Value of Lifetime Social Benefits by Alternative
(Millions of 2007 Dollars)
(3 percent discount rate)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars										
Preferred Alternative	$6,074	$11,565	$18,571	$25,562	$30,914	$35,926	$43,274	$51,062	$59,934	$282,883
1% Annual Increase	$1,771	$3,417	$5,735	$7,631	$9,227	$10,569	$12,741	$14,897	$17,262	$83,251
2% Annual Increase	$3,252	$6,504	$10,515	$14,545	$18,072	$21,206	$23,843	$27,838	$31,092	$156,867
3% Annual Increase	$5,030	$10,389	$16,307	$22,266	$27,156	$31,431	$35,548	$41,065	$47,611	$236,804
4% Annual Increase	$7,617	$13,946	$20,851	$28,440	$33,784	$38,484	$43,980	$52,260	$59,842	$299,203
5% Annual Increase	$10,381	$17,331	$24,910	$33,379	$40,555	$45,125	$51,506	$64,971	$73,946	$362,105
6% Annual Increase	$13,117	$20,558	$28,165	$37,792	$44,011	$49,223	$57,454	$75,403	$86,456	$412,179
7% Annual Increase	$15,194	$23,103	$30,866	$40,631	$45,868	$52,846	$64,667	$80,171	$92,319	$445,666
Max Net Benefits	$16,739	$19,816	$25,943	$30,567	$34,927	$37,039	$40,161	$43,655	$47,505	$296,352
Total Cost = Total Benefit	$19,034	$23,285	$28,004	$33,132	$39,869	$45,981	$54,779	$62,676	$69,636	$376,397

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks										
Preferred Alternative	$1,980	$5,906	$12,484	$17,198	$24,377	$27,553	$30,344	$34,672	$39,161	$193,675
1% Annual Increase	$2,123	$3,941	$7,462	$8,778	$11,210	$12,312	$13,346	$13,881	$14,227	$87,280
2% Annual Increase	$3,751	$6,908	$11,984	$14,716	$18,560	$20,333	$22,351	$24,374	$25,956	$148,932
3% Annual Increase	$5,580	$10,290	$16,248	$20,981	$26,256	$29,437	$31,574	$34,862	$38,168	$213,396
4% Annual Increase	$8,097	$13,331	$20,605	$26,590	$32,929	$36,853	$40,310	$43,393	$48,366	$270,474
5% Annual Increase	$10,100	$15,958	$23,523	$30,400	$38,204	$42,299	$45,811	$51,821	$57,058	$315,176
6% Annual Increase	$12,809	$18,227	$26,811	$34,559	$40,203	$44,032	$48,166	$53,460	$59,256	$337,524
7% Annual Increase	$13,928	$19,529	$28,270	$35,675	$40,352	$46,412	$50,875	$57,342	$61,119	$353,501
Max Net Benefits	$17,972	$20,646	$26,584	$32,005	$38,362	$40,849	$44,947	$49,685	$55,460	$326,511
Total Cost = Total Benefit	$18,038	$20,568	$26,474	$31,989	$38,463	$40,904	$45,676	$50,398	$56,595	$329,104

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$8,054	$17,471	$31,055	$42,759	$55,291	$63,479	$73,618	$85,734	$99,095	$476,558
1% Annual Increase	$3,894	$7,358	$13,197	$16,410	$20,436	$22,881	$26,087	$28,778	$31,489	$170,531
2% Annual Increase	$7,003	$13,412	$22,499	$29,261	$36,631	$41,538	$46,194	$52,212	$57,049	$305,799
3% Annual Increase	$10,611	$20,679	$32,555	$43,247	$53,412	$60,868	$67,122	$75,927	$85,778	$450,200
4% Annual Increase	$15,715	$27,276	$41,455	$55,030	$66,712	$75,337	$84,290	$95,653	$108,208	$569,677
5% Annual Increase	$20,482	$33,290	$48,432	$63,779	$78,759	$87,425	$97,317	$116,793	$131,004	$677,280
6% Annual Increase	$25,926	$38,785	$54,975	$72,352	$84,214	$93,255	$105,620	$128,863	$145,712	$749,703
7% Annual Increase	$29,122	$42,632	$59,136	$76,306	$86,220	$99,258	$115,542	$137,513	$153,438	$799,167
Max Net Benefits	$34,711	$40,462	$52,527	$62,572	$73,289	$77,888	$85,108	$93,340	$102,964	$622,863
Total Cost = Total Benefit	$37,073	$43,853	$54,478	$65,121	$78,331	$86,885	$100,455	$113,074	$126,231	$705,501

Table VIII-20
Present Value of Lifetime Social Benefits by Alternative
(Millions of 2009 dollars)
(7 percent discount rate)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$4,960	$9,446	$15,186	$20,906	$25,309
1% Annual Increase	$1,449	$2,792	$4,688	$6,239	$7,552
2% Annual Increase	$2,654	$5,308	$8,592	$11,887	$14,789
3% Annual Increase	$4,112	$8,491	$13,340	$18,213	$22,238
4% Annual Increase	$6,220	$11,389	$17,054	$23,264	$27,661
5% Annual Increase	$8,477	$14,145	$20,359	$27,292	$33,198
6% Annual Increase	$10,711	$16,780	$23,017	$30,904	$36,030
7% Annual Increase	$12,412	$18,874	$25,245	$33,243	$37,564
Max Net Benefits	$13,553	$15,998	$21,039	$24,905	$28,393
Total Cost = Total Benefit	$15,541	$19,006	$22,812	$27,049	$32,566
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$29,447	$35,453	$41,887	$49,224	$231,819
1% Annual Increase	$8,659	$10,453	$12,238	$14,195	$68,266
2% Annual Increase	$17,380	$19,559	$22,866	$25,567	$128,603
3% Annual Increase	$25,765	$29,164	$33,728	$39,138	$194,190
4% Annual Increase	$31,547	$36,052	$42,887	$49,174	$245,249
5% Annual Increase	$36,978	$42,253	$53,387	$60,826	$296,914
6% Annual Increase	$40,380	$47,189	$62,194	$71,387	$338,593
7% Annual Increase	$43,334	$53,166	$66,132	$76,339	$366,309
Max Net Benefits	$30,124	$32,432	$35,533	$38,781	$240,758
Total Cost = Total Benefit	$35,922	$43,437	$50,230	$55,911	$302,474

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks										
Preferred Alternative	$1,591	$4,747	$10,009	$13,820	$19,596	$22,176	$24,439	$27,942	$31,571	$155,891
1% Annual Increase	$1,702	$3,163	$5,994	$7,063	$9,025	$9,924	$10,767	$11,205	$11,495	$70,338
2% Annual Increase	$3,003	$5,539	$9,611	$11,819	$14,921	$16,372	$18,017	$19,645	$20,942	$119,869
3% Annual Increase	$4,468	$8,259	$13,029	$16,856	$21,096	$23,679	$25,418	$28,089	$30,754	$171,647
4% Annual Increase	$6,482	$10,694	$16,523	$21,368	$26,459	$29,642	$32,440	$34,952	$38,970	$217,530
5% Annual Increase	$8,086	$12,799	$18,859	$24,428	$30,730	$34,056	$36,894	$41,752	$45,985	$253,588
6% Annual Increase	$10,253	$14,603	$21,484	$27,760	$32,320	$35,431	$38,788	$43,082	$47,751	$271,471
7% Annual Increase	$11,148	$15,646	$22,642	$28,646	$32,406	$37,301	$40,921	$46,168	$49,229	$284,108
Max Net Benefits	$12,389	$14,670	$19,604	$22,986	$28,349	$30,138	$32,226	$33,809	$35,078	$229,249
Total Cost = Total Benefit	$14,516	$16,521	$21,272	$25,733	$30,804	$32,807	$36,748	$40,654	$45,668	$264,722

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$6,551	$14,193	$25,196	$34,726	$44,905	$51,623	$59,892	$69,829	$80,795	$387,710
1% Annual Increase	$3,152	$5,955	$10,683	$13,302	$16,577	$18,584	$21,220	$23,443	$25,690	$138,604
2% Annual Increase	$5,657	$10,847	$18,203	$23,706	$29,711	$33,751	$37,576	$42,511	$46,509	$248,472
3% Annual Increase	$8,580	$16,751	$26,369	$35,068	$43,334	$49,444	$54,582	$61,817	$69,892	$365,837
4% Annual Increase	$12,703	$22,082	$33,578	$44,633	$54,119	$61,189	$68,492	$77,839	$88,144	$462,779
5% Annual Increase	$16,562	$26,944	$39,217	$51,720	$63,927	$71,034	$79,147	$95,138	$106,811	$550,502
6% Annual Increase	$20,965	$31,383	$44,501	$58,663	$68,349	$75,811	$85,977	$105,276	$119,138	$610,064
7% Annual Increase	$23,560	$34,521	$47,887	$61,889	$69,971	$80,636	$94,087	$112,300	$125,568	$650,417
Max Net Benefits	$25,942	$30,668	$40,644	$47,891	$56,742	$60,262	$64,658	$69,342	$73,859	$470,007
Total Cost = Total Benefit	$30,056	$35,527	$44,084	$52,782	$63,371	$68,730	$80,185	$90,884	$101,579	$567,197

Table VIII-21
Fuel Savings over Lifetimes of Model Year 2017-2025 Passenger Cars and Light Trucks with Alternative Increases in CAFE Standards
(Millions of gallons)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	2,120	3,995	6,368	8,639	10,484
1% Annual Increase	621	1,192	1,997	2,624	3,135
2% Annual Increase	1,140	2,266	3,636	4,964	6,091
3% Annual Increase	1,757	3,581	5,558	7,516	9,063
4% Annual Increase	2,654	4,779	7,091	9,577	11,373
5% Annual Increase	3,716	6,078	8,600	11,389	13,971
6% Annual Increase	4,652	7,262	9,845	13,094	15,061
7% Annual Increase	5,246	8,029	10,655	13,940	15,579
Max Net Benefits (3% Discount Rate)	5,820	6,941	8,999	10,469	11,814
Max Net Benefits (7% Discount Rate)	5,773	6,868	8,933	10,438	11,744
TC = TB (3% Discount Rate)	6,717	8,142	9,675	11,384	13,556
TC = TB (7% Discount Rate)	6,716	8,142	9,678	11,362	13,519
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	12,056	14,414	16,809	19,690	94,575
1% Annual Increase	3,570	4,257	4,930	5,685	28,010
2% Annual Increase	7,077	7,878	9,110	10,125	52,288
3% Annual Increase	10,423	11,681	13,374	15,536	78,489
4% Annual Increase	12,829	14,603	17,266	19,679	99,851
5% Annual Increase	15,438	17,431	21,605	24,369	122,597
6% Annual Increase	16,591	19,112	24,243	27,619	137,479
7% Annual Increase	17,753	21,254	25,655	29,078	147,189
Max Net Benefits (3% Discount Rate)	12,423	13,343	14,360	15,553	99,722
Max Net Benefits (7% Discount Rate)	12,344	13,162	14,262	15,483	99,007
TC = TB (3% Discount Rate)	15,492	18,156	20,546	22,717	126,385
TC = TB (7% Discount Rate)	14,745	17,518	19,996	22,123	123,799

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	685	2,026	4,297	5,817	8,183
1% Annual Increase	741	1,373	2,572	2,987	3,780
2% Annual Increase	1,315	2,399	4,133	5,028	6,275
3% Annual Increase	1,950	3,542	5,579	7,134	8,849
4% Annual Increase	2,826	4,640	7,119	9,019	11,089
5% Annual Increase	3,526	5,580	8,172	10,389	13,000
6% Annual Increase	4,478	6,559	9,466	11,955	13,935
7% Annual Increase	4,883	7,011	9,955	12,382	13,886
Max Net Benefits (3% Discount Rate)	6,293	7,322	9,312	11,063	13,088
Max Net Benefits (7% Discount Rate)	5,406	6,490	8,614	9,916	12,059
TC = TB (3% Discount Rate)	6,294	7,325	9,305	11,076	13,148
TC = TB (7% Discount Rate)	6,326	7,342	9,331	11,098	13,114
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	9,149	9,991	11,310	12,754	64,212
1% Annual Increase	4,107	4,415	4,562	4,640	29,178
2% Annual Increase	6,792	7,388	8,013	8,458	49,802
3% Annual Increase	9,813	10,431	11,408	12,519	71,224
4% Annual Increase	12,283	13,425	14,314	15,848	90,564
5% Annual Increase	14,231	15,289	17,190	18,787	106,162
6% Annual Increase	15,139	16,351	17,907	19,709	115,499
7% Annual Increase	15,733	17,048	18,948	20,079	119,925
Max Net Benefits (3% Discount Rate)	13,776	14,995	16,387	18,177	110,413
Max Net Benefits (7% Discount Rate)	12,675	13,430	13,957	14,335	96,881
TC = TB (3% Discount Rate)	13,824	15,254	16,708	18,597	111,531
TC = TB (7% Discount Rate)	13,792	15,249	16,727	18,616	111,593

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	2,805	6,022	10,665	14,456	18,667	21,205	24,405	28,119	32,444	158,787
1% Annual Increase	1,362	2,565	4,569	5,611	6,915	7,677	8,672	9,491	10,325	57,188
2% Annual Increase	2,456	4,665	7,769	9,992	12,366	13,870	15,267	17,124	18,583	102,090
3% Annual Increase	3,707	7,123	11,138	14,649	17,912	20,235	22,112	24,781	28,055	149,713
4% Annual Increase	5,480	9,419	14,210	18,597	22,462	25,112	28,028	31,579	35,528	190,415
5% Annual Increase	7,242	11,657	16,772	21,778	26,971	29,669	32,720	38,795	43,157	228,759
6% Annual Increase	9,131	13,821	19,311	25,049	28,996	31,730	35,463	42,150	47,327	252,978
7% Annual Increase	10,129	15,040	20,610	26,322	29,465	33,487	38,302	44,603	49,157	267,115
Max Net Benefits (3% Discount Rate)	12,113	14,263	18,311	21,532	24,902	26,199	28,337	30,747	33,730	210,134
Max Net Benefits (7% Discount Rate)	11,179	13,358	17,548	20,354	23,803	25,019	26,591	28,219	29,818	195,889
TC = TB (3% Discount Rate)	13,011	15,467	18,980	22,460	26,704	29,316	33,410	37,254	41,314	237,916
TC = TB (7% Discount Rate)	13,042	15,483	19,009	22,459	26,633	28,537	32,767	36,722	40,739	235,392

Table VIII-22
Net Change in Electricity Consumption over Lifetimes of Model Year 2017-2025 Passenger Cars and Light Trucks with Alternative Increases in CAFE Standards
(in GW-h)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars										
Preferred Alternative	-6.8	-7.0	16.9	185.5	479.4	494.8	5,165.9	5,850.6	16,280.9	28,460.3
2% Annual Increase	-6.8	-7.0	-7.2	-7.0	-7.2	-7.2	63.4	214.0	1,659.0	1,893.9
3% Annual Increase	-6.8	-7.0	-7.2	16.6	17.0	18.2	89.6	309.1	4,580.3	5,009.8
4% Annual Increase	-6.8	-7.0	-7.2	424.8	965.3	969.8	4,872.7	7,197.9	16,420.3	30,829.9
5% Annual Increase	10.3	813.9	939.0	1,654.7	4,774.4	6,870.7	12,033.9	24,720.4	35,241.4	87,058.6
6% Annual Increase	10.3	813.9	1,135.4	5,980.6	8,528.9	12,199.0	20,434.3	41,327.6	57,076.2	147,506.1
7% Annual Increase	576.6	2,132.6	2,568.3	10,326.0	11,883.1	19,360.3	35,126.2	53,854.8	68,386.4	204,214.3
Max Net Benefits (3% Discount Rate)	910.3	922.6	4,160.3	4,693.2	5,106.8	5,343.6	5,817.0	6,393.3	10,013.7	43,360.8
Max Net Benefits (7% Discount Rate)	910.3	922.6	4,160.3	4,693.2	5,106.8	5,343.6	5,817.0	6,393.3	9,537.0	42,884.1
Total Cost = Total Benefit (3% Discount Rate)	910.3	1,822.3	1,834.9	1,892.8	2,652.2	8,075.0	17,796.8	22,179.7	30,782.1	87,946.1
Total Cost = Total Benefit (7% Discount Rate)	910.3	1,822.3	1,834.9	1,892.8	2,546.2	3,684.4	13,414.6	17,800.8	26,103.5	70,009.8

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	0	0	0	0	0
2% Annual Increase	0	0	0	0	0
3% Annual Increase	0	0	0	0	0
4% Annual Increase	0	0	0	0	0
5% Annual Increase	0	0	0	1.7	1.6
6% Annual Increase	0	733.8	708.6	727.2	724.6
7% Annual Increase	0	733.8	708.6	727.2	724.6
Max Net Benefits (3% Discount Rate)	0	771.9	746.2	736.9	734.2
Max Net Benefits (7% Discount Rate)	0	0.0	0.0	1.7	1.6
Total Cost = Total Benefit (3% Discount Rate)	0	776.8	751.1	736.9	734.3
Total Cost = Total Benefit (7% Discount Rate)	0	776.8	751.1	736.9	734.3
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	0	0	0	0	0
2% Annual Increase	0	0	0	0	0
3% Annual Increase	0	0	0	0	0
4% Annual Increase	0	0	0	280.3	280.3
5% Annual Increase	457.5	2,041.7	4,683.9	4,709.1	11,895.5
6% Annual Increase	1,187.7	3,355.7	5,051.0	8,088.8	20,577.5
7% Annual Increase	5,011.4	6,448.3	8,993.5	9,199.0	32,546.4
Max Net Benefits (3% Discount Rate)	741.5	2,211.3	2,267.1	2,271.7	10,480.8
Max Net Benefits (7% Discount Rate)	1.6	1.5	1.7	1.7	9.8
Total Cost = Total Benefit (3% Discount Rate)	741.5	2,211.3	3,815.6	4,447.5	14,215.1
Total Cost = Total Benefit (7% Discount Rate)	741.5	2,211.3	3,815.6	4,447.5	14,215.1

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	-6.8	-7.0	16.9	185.5	479.4	494.8	5,165.9	5,850.6	16,280.9	28,460.3
2% Annual Increase	-6.8	-7.0	-7.2	-7.0	-7.2	-7.2	63.4	214.0	1,659.0	1,893.9
3% Annual Increase	-6.8	-7.0	-7.2	16.6	17.0	18.2	89.6	309.1	4,580.3	5,009.8
4% Annual Increase	-6.8	-7.0	-7.2	424.8	965.3	969.8	4,872.7	7,197.9	16,700.6	31,110.1
5% Annual Increase	10.3	813.9	939.0	1,656.4	4,775.9	7,328.2	14,075.6	29,404.3	39,950.5	98,954.1
6% Annual Increase	10.3	1,547.7	1,844.0	6,707.7	9,253.5	13,386.7	23,790.1	46,378.6	65,165.0	168,083.5
7% Annual Increase	576.6	2,866.4	3,276.9	11,053.2	12,607.7	24,371.7	41,574.5	62,848.3	77,585.4	236,760.7
Max Net Benefits (3% Discount Rate)	910.3	1,694.5	4,906.6	5,430.1	5,841.1	6,085.1	8,028.3	8,660.4	12,285.4	53,841.6
Max Net Benefits (7% Discount Rate)	910.3	922.6	4,160.3	4,694.9	5,108.5	5,345.2	5,818.5	6,394.9	9,538.7	42,893.9
Total Cost = Total Benefit (3% Discount Rate)	910.3	2,599.1	2,586.0	2,629.7	3,386.5	8,816.5	20,008.1	25,995.3	35,229.6	102,161.2
Total Cost = Total Benefit (7% Discount Rate)	910.3	2,599.1	2,586.0	2,629.7	3,280.5	4,426.0	15,625.9	21,616.4	30,551.0	84,224.9

H. Social Benefits, Private Benefits, and Potential Unquantified Consumer Welfare Impacts of the Proposed Standards

There are two viewpoints for evaluating the costs and benefits of the increase in CAFE standards: the private perspective of vehicle buyers themselves on the higher fuel economy levels that the rule would require, and the economy-wide or "social" perspective on the costs and benefits of requiring higher fuel economy. In order to appreciate how these viewpoints may diverge, it is important to distinguish between costs and benefits that are "private" and costs and benefits that are "social," The agency's analysis of benefits and costs from requiring higher fuel efficiency, presented above, includes several categories of benefits (identified as "social benefits") that are not limited to automobile purchasers, and that extend throughout the U.S. economy. Examples of these benefits include reductions in the energy security costs associated with U.S. petroleum imports, and in the economic damages expected to result from air pollution (including but not limited to climate change). In contrast, other categories of benefits—principally future fuel savings projected to result from higher fuel economy, but also for example time savings—will be experienced exclusively by the initial purchasers and subsequent owners of vehicle models whose fuel economy manufacturers elect to improve ("private benefits").

The economy-wide or "social" benefits from requiring higher fuel economy represent an important share of the total economic benefits from raising CAFE standards. At the same time, NHTSA estimates that benefits *to vehicle buyers themselves* will significantly exceed vehicle manufacturers' costs for complying with the stricter fuel economy standards this rule establishes. In short, consumers will benefit on net. Since the agency also assumes that the costs of new technologies manufacturers will employ to improve fuel economy will ultimately be borne by vehicle buyers in the form of higher purchase prices, NHTSA concludes that the benefits to potential vehicle buyers from requiring higher fuel efficiency will far outweigh the costs they will be required to pay to obtain it. NHTSA recognizes that this conclusion raises certain issues, addressed directly below; NHTSA also seeks public comment on its discussion here.

As an illustration, Tables VIII-23 and VIII-24 report the agency's estimates of the average lifetime values of fuel savings for MY 2017-2025 passenger cars and light trucks calculated using future retail fuel prices (that is, inclusive of fuel taxes), which are those likely to be used by vehicle buyers to project the value of fuel savings they expect from higher fuel economy. The tables compare NHTSA's estimates of the average lifetime value of fuel savings for cars and light trucks to the price increases projected to result from manufacturers' efforts to recover their costs for complying with increased CAFE standards for those model years by increasing vehicles' sales prices. As the tables show, the agency's estimates of the present value of lifetime fuel savings (discounted at both 3 and 7 percent rates) outweigh projected vehicle price increases for both cars and light trucks in every model year, even under the assumption that all of manufacturers' technology outlays are passed on to buyers in the form of higher selling prices for new cars and light trucks. By model year 2025, NHTSA projects that average lifetime fuel savings will exceed the average price increase by more than $3,000 for cars and over $4,900 for light trucks assuming a 3 percent discount rate; if a 7 percent discount rate is applied, fuel savings will exceed average price increases by more than $2,000 for cars and slightly more than $3,600 for light trucks.

Table VIII-23
Net Present Value of Lifetime[379] Fuel Savings vs. Avg. Vehicle Price Increase Under Preferred Alternative, 3% Discount Rate

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Value of Fuel Savings	$605	$1,157	$1,842	$2,444	$2,904
Average Price Increase	$141	$320	$529	$767	$977
Difference	$464	$837	$1,313	$1,677	$1,927
		MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars					
Value of Fuel Savings		$3,291	$3,870	$4,425	$5,079
Average Price Increase		$1,122	$1,424	$1,688	$1,926
Difference		$2,168	$2,446	$2,737	$3,153
	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Value of Fuel Savings	$328	$1,003	$2,177	$2,960	$4,132
Average Price Increase	$57	$178	$359	$524	$755
Difference	$271	$824	$1,819	$2,436	$3,377
		MY 2022	MY 2023	MY 2024	MY 2025
Light Trucks					
Value of Fuel Savings		$4,637	$5,110	$5,833	$6,553
Average Price Increase		$863	$976	$1,141	$1,348
Difference		$3,774	$4,134	$4,692	$5,205

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[379] For Tables VIII-23 and VIII-24, the lifetime of vehicles is 26 years for passenger cars and 36 years for light trucks. Note that a very small percentage of the fuel savings benefit occurs beyond roughly 15 years, as vehicle survivability declines and decreased VMT due to vehicle age greatly diminish expected per-vehicle VMT in these later years.

Table VIII-24
Net Present Value of Lifetime Fuel Savings vs. Avg. Vehicle Price Increase
Under Preferred Alternative, 7% Discount Rate

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Value of Fuel Savings	$483	$924	$1,474	$1,955	$2,326
Average Price Increase	$141	$320	$529	$767	$977
Difference	$342	$604	$945	$1,188	$1,349
		MY 2022	MY 2023	MY 2024	MY 2025
Passenger Cars					
Value of Fuel Savings		$2,638	$3,101	$3,549	$4,079
Average Price Increase		$1,122	$1,424	$1,688	$1,926
Difference		$1,515	$1,678	$1,861	$2,153
	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Value of Fuel Savings	$256	$783	$1,703	$2,316	$3,236
Average Price Increase	$57	$178	$359	$524	$755
Difference	$199	$605	$1,344	$1,792	$2,481
		MY 2022	MY 2023	MY 2024	MY 2025
Light Trucks					
Value of Fuel Savings		$3,635	$4,008	$4,579	$5,148
Average Price Increase		$863	$976	$1,141	$1,348
Difference		$2,771	$3,032	$3,438	$3,800

Assuming these comparisons are accurate, they raise the question of why current vehicle purchasing patterns do not result in average fuel economy levels approaching those that this rule would require, and why stricter CAFE standards should be necessary to increase the fuel economy of new cars and light trucks. They also raise the question of why manufacturers do not elect to provide higher fuel economy even in the absence of increases in CAFE standards, since the comparisons in the preceding tables suggest that doing so would *reduce* the effective price of purchasing many new vehicle models, and thus increase sales of new vehicles. More specifically, why would potential buyers of new vehicles hesitate to make investments in vehicles with higher fuel economy that would produce the substantial economic returns illustrated by the comparisons presented in Tables VIII-23 and VIII-24? And why would manufacturers voluntarily forego opportunities to increase the attractiveness, value, and competitive positioning of their car and light truck models by improving their fuel economy?

One explanation for this apparent paradox involves imperfections in the relevant market. Some of these imperfections might stem from standard market failures (such as an absence of adequate information); some of them involve behavioral findings (including, for example, a lack of sufficient attention to long-term savings, or a lack of salience, at the time of purchase, of relevant benefits, including fuel and time savings). A subset of the theoretical and empirical research suggests that many consumers do not make energy-efficient investments even when those investments would pay off in the relatively short-term,[380] in line with related findings that consumers may underweight benefits and costs that are less salient or that will be realized only in the future.[381]

One explanation for why this situation might persist is that the market for vehicle fuel economy does not appear to work perfectly, in which case properly designed CAFE standards would be expected to increase consumer welfare. Some of these imperfections might stem from standard market failures, such as limited availability of information to consumers about the value of higher fuel economy.[382] It is true, of course, that such information is technically available and that new fuel economy labels, emphasizing economic effects, will provide a wide range of relevant information. Other explanations would point to phenomena observed elsewhere in the field of behavioral economics, including loss aversion, inadequate consumer attention to long-term savings, or a lack of salience of relevant benefits (such as fuel savings, or time savings associated with refueling) to consumers at the time they make purchasing decisions. Both theoretical and empirical research suggests that many consumers are unwilling to make energy-efficient investments even when those investments appear to pay off in the relatively short-term.[380] This research is in line with related findings that consumers may undervalue benefits or costs that are less salient, or that they will realize only in the future.[383]

Previous research provides some support for the agency's conclusion that the benefits buyers will receive from requiring manufacturers to increase fuel economy outweigh the costs they will pay to acquire those benefits, even if private markets have not provided that amount of fuel economy. This research identifies aspects of normal behavior that may explain the market not providing vehicles whose higher fuel economy appears to offer an attractive economic return. For example, consumers' aversion to the prospect of losses ("loss aversion"), and especially certain, immediate losses, may affect their decisions when they also have a sense of uncertainty about the value of future fuel savings. Loss aversion, accompanied with a sense of uncertainty

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[380] Jaffe, A. B., and Stavins, R. N. (1994). The Energy Paradox and the Diffusion of Conservation Technology. Resource and Energy Economics, 16(2); see Hunt Alcott and Nathan Wozny, Gasoline Prices, Fuel Economy, and the Energy Paradox (2010, available at http://www.sciencedirect.com/science/article/B6VFJ-45DMPNK-7/2/0d3440e9948aab163f984aeb7c8472a7 (last accessed November 14, 2011).

[381] Hossain, Janjim, and John Morgan (2009). ". . . Plus Shipping and Handling: Revenue (Non) Equivalence in Field Experiments on eBay," Advances in Economic Analysis and Policy vol. 6; Barber, Brad, Terrence Odean, and Lu Zheng (2005). Available at http://faculty.haas.berkeley.edu/rjmorgan/eBay.pdf (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131.

[382] "Out of Sight, Out of Mind: The Effects of Expenses on Mutual Fund Flows," Journal of Business vol. 78, no. 6, pp. 2095-2020. Available at http://faculty.haas.berkeley.edu/odean/papers/MutualFunds/Out%20of%20Sight%200112281.pdf (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131.

[383] Mutulinggan, S., C. Corbett, S. Benartzi, and B. Oppenheim. "Investment in Energy Efficiency by Small and Medium-Size Firms: An Empirical Analysis of the Adoption of Process Improvement Recommendations" (2011)m available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1947330 (last accessed November 11, 2011).

about gains, may make purchasing a more fuel-efficient vehicle seem unattractive to some potential buyers, even when doing so *is* likely to be a sound economic decision. As an illustration, Greene et al. (2009) calculate that the expected net present value of increasing the fuel economy of a passenger car from 28 to 35 miles per gallon falls from $405 when calculated using standard net present value calculations, to nearly zero when uncertainty regarding future cost savings and buyers' reluctance to accept the risk of losses are taken into account.[384]

The well-known finding that as gas prices rise, consumers show more willingness to pay for fuel-efficient vehicles is not necessarily inconsistent with the possibility that many consumers undervalue potential savings in gasoline costs and fuel economy when purchasing new vehicles. In ordinary circumstances, such costs may be a relatively "shrouded" attribute in consumers' decisions, in part because the savings from purchasing a more fuel efficient vehicle are cumulative and extend over a significant period of time. At the same time, it may be difficult for potential buyers to disentangle the cost of purchasing a more fuel-efficient vehicle from its overall purchase price, or to isolate the value of higher fuel economy from accompanying differences in other vehicle attributes. This possibility is consistent with recent evidence to the effect that many consumers are willing to pay less than $1 upfront to obtain a $1 reduction in the discounted present value of future gasoline costs.[385]

Some research suggests that the market's apparent unwillingness to provide more fuel efficient vehicles stems from consumers' inability to value future fuel savings correctly. For example, Larrick and Soll (2008) find evidence that consumers do not understand how to translate changes in fuel economy, which is denominated in miles per gallon (MPG), into resulting changes in fuel consumption, measured for example in gallons per 100 miles travelled or per month or year.[386] It is true that the recently redesigned fuel economy label should help overcome this difficulty, because it draws attention to purely economic effects of fuel economy, but MPG remains a prominent measure. Sanstad and Howarth (1994) argue that consumers often resort to imprecise but convenient rules of thumb to compare vehicles that offer different fuel economy ratings, and that this can cause many buyers to underestimate the value of fuel savings, particularly from significant increases in fuel economy.[387] If the behavior identified in these studies is widespread, then the agency's estimates suggesting that the benefits to vehicle owners from requiring higher

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[384] Greene, D., J. German, and M. Delucchi (2009). "Fuel Economy: The Case for Market Failure" in Reducing Climate Impacts in the Transportation Sector, Sperling, D., and J. Cannon, eds. Springer Science. Surprisingly, the authors find that uncertainty regarding the future price of gasoline appears to be less important than uncertainty surrounding the expected lifetimes of new vehicles. (Docket NHTSA–2009–0059–0154). On loss aversion in general, and its relationship to prospect theory (which predicts that certain losses will loom larger than probabilistic gains of higher expected value), see Kahneman.

[385] *See, e.g.,* Alcott and Wozny. On shrouded attributes and their importance, see Gabaix, Xavier, and David Laibson. 2006. "Shrouded Attributes, Consumer Myopia, and Information Suppression in Competitive Markets." *Quarterly Journal of Economics* 121(2): 505-540. Available at http://www.economics.harvard.edu/faculty/laibson/files/Shrouded.pdf or Docket No. NHTSA-2010-0131.

[386] Larrick, R. P., and J.B. Soll (2008). "The MPG illusion." *Science* 320: 1593-1594. Available at http://www.sciencemag.org/content/320/5883/1593.full?ijkey=3pScQm7pQBzqs&keytype=ref&siteid=sci (last accessed November 14, 2011) or Docket No. NHTSA-2011-0131

[387] Sanstad, A., and R. Howarth (1994). " 'Normal' Markets, Market Imperfections, and Energy Efficiency." Energy Policy 22(10): 811–818. Available at http://www.sciencedirect.com/science/article/pii/0301421594901392 (last accessed November 14, 2011)

fuel economy significantly exceed the costs of providing it may be consistent with private markets not providing that fuel economy level.

The agency projects that the typical vehicle buyer will experience net savings from the proposed standards, yet it is not simple to reconcile this projection with the fact that the average fuel economy of new vehicles sold currently falls well short of the level those standards would require. The foregoing discussion offers several possible explanations. One possible explanation for this apparent inconsistency is that many of the technologies projected by the agency to be available through MY2025 offer significantly improved efficiency per unit of cost, yet were not available for application to new vehicles sold currently. Another is that the perceived and real values of future savings resulting from the proposed standards will vary widely among potential vehicle buyers. When they purchase a new vehicle, some buyers value fuel economy very highly, and others value fuel economy very little, if at all. These differences undoubtedly reflect variation in the amount they drive, differences in their driving styles affect the fuel economy they expect to achieve, and varying expectations about future fuel prices, but they may also partly reflect differences in buyers' understanding of what increased fuel economy is likely to mean to them financially, or in buyers' preferences for paying lower prices today versus anticipated savings over the future.

Unless the agency has overestimated their *average* value, however, the fact that the value of fuel savings varies among potential buyers cannot explain why typical buyers do not currently purchase what appear to be cost- saving increases in fuel economy. A possible explanation for this situation is that the effects of differing fuel economy levels are relatively modest when compared to those provided by other, more prominent features of new vehicles, such as passenger and cargo-carrying capacity, performance, or safety. In this situation, it may simply not be in many shoppers' interest to spend the time and effort necessary to determine the economic value of higher fuel economy, to isolate the component of a new vehicle's selling price that is related to its fuel economy, and compare these two. (This possibility is consistent with the view that fuel economy is a relatively "shrouded" attribute.) In this case, the agency's estimates of the *average* value of fuel savings that will result from requiring cars and light trucks to achieve higher fuel economy may be correct, yet those savings may not be large enough to lead a sufficient number of buyers to purchase vehicles with higher fuel economy to raise average fuel economy above its current levels.

Defects in the market for cars and light trucks could also lead manufacturers to undersupply fuel economy, even in cases where many buyers were willing to pay the increased prices necessary to compensate manufacturers for providing it. To be sure, the market for new automobiles as a whole exhibits a great deal of competition. But this apparently vigorous competition among manufacturers may not extend to the provision of some individual vehicle attributes. Incomplete or "asymmetric" access to information about vehicle attributes such as fuel economy—whereby manufacturers of new cars and light trucks or sellers of used models have more complete knowledge about vehicles' actual fuel economy performance than is available to their potential buyers—may also prevent sellers of new or used vehicles from being able to capture its full value. In this situation, the level of fuel efficiency provided in the markets for new or used vehicles might remain persistently lower than that demanded by well-informed potential buyers.

Constraints on the combinations of fuel economy, carrying capacity, and performance that manufacturers can offer in individual vehicle models using current technologies undoubtedly limit the range of fuel economy available within certain vehicle classes, particularly those including larger vehicles. However, it is also possible that deliberate decisions by manufacturers of cars and light trucks further limit the range of fuel economy available to buyers within individual vehicle market segments, such as large automobiles, SUVs, or minivans. Manufacturers may deliberately limit the range of fuel economy levels they offer in those market segments (by choosing not to invest in fuel economy and investing instead in providing a range of other vehicle attributes) because they underestimate the premiums that prospective buyers of those models are willing to pay for improved fuel economy, and thus mistakenly believe it will be unprofitable for them to offer more fuel-efficient models within those segments. Of course, this possibility is most realistic if it is also assumed that buyers are imperfectly informed, or if fuel economy savings are not sufficiently salient to shoppers in those particular market segments. As an illustration, once a potential buyer has decided to purchase a minivan, the range of highway fuel economy ratings among current models extends from 22 to 28 mpg, while their combined city and highway ratings extend only from 18 to 20 mpg.[388] If this phenomenon is widespread, the average fuel efficiency of their entire new vehicle fleet could remain below the levels that potential buyers demand and are willing to pay for.

Another possible explanation for the paradox posed by buyers' apparent unwillingness to invest in higher fuel economy when it appears to offer such large financial returns is that NHTSA's estimates of benefits and costs from requiring manufacturers to improve fuel efficiency do not match potential buyers' assessment of the likely benefits and costs from purchasing models with higher fuel economy ratings. This could occur because the agency's underlying assumptions about some of the factors that affect the value of fuel savings differ from those made by potential buyers, because NHTSA has used different estimates for some components of the benefits from saving fuel from those of buyers, or simply because the agency has failed to account for some potential costs of achieving higher fuel economy.

For example, buyers may not value increased fuel economy as highly as the agency's calculations suggest, because they have shorter time horizons than the full vehicle lifetimes NHTSA uses in these calculations, or because they discount future fuel savings using higher rates than those prescribed by OMB for evaluating Federal regulations. Potential buyers may also anticipate lower fuel prices in the future than those forecast by the Energy Information Administration, or may expect larger differences between vehicles' MPG ratings and their own actual on-road fuel economy than the 20 percent gap (30 percent for HEVs) the agency estimates.

To illustrate the first of these possibilities, Table VIII-25 shows the effect of differing assumptions about vehicle buyers' time horizons for assessing the value of future fuel savings. Specifically, the table compares the average value of fuel savings from purchasing a MY 2025 car or light truck when fuel savings are evaluated over different time horizons to the estimated increase in its price.

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[388] This is the range of combined city and highway fuel economy levels from lowest (Toyota Sienna AWD) to highest (Honda Odyssey) available for model year 2010; http://www.fueleconomy.gov/feg/bestworstEPAtrucks.htm (last accessed September 26, 2011).

Unlike Tables VIII-23 and VIII-24, Table VIII-25 looks at the value of fuel savings only for the vehicle lifetime as anticipated by the consumer, that is, 14 years for passenger cars and 16 years for light trucks. Table VIII-25 shows that over the consumer's anticipated lifetime of model year 2025 vehicles, NHTSA projects that average lifetime fuel savings will exceed the average price increase by a bit less than $2,800 for passenger cars and over $4,500 for light trucks assuming a 3 percent discount rate; if a 7 percent discount rate is applied, fuel savings will exceed average price increases by more than $1,900 for cars and nearly $3,300 for light trucks.

If buyers are instead assumed to evaluate fuel savings over a 10-year time horizon, however, the present value of fuel savings exceeds the projected price increase for a MY 2025 passenger car by about $2,000 and a bit less than $3,400 for a MY 2025 light truck, assuming a 3 percent discount rate. If a 7 percent discount rate is assumed, the corresponding values are somewhat more than $1,400 for passenger cars and a bit less than $2,400 for light trucks.

Finally, Table VIII-25 shows that under the assumption that buyers value fuel savings only over the length of time for which they typically finance new car purchases (slightly more than 5 years during 2010), the value of fuel savings, valued according to a 3 percent discount rate, exceeds the estimated increase in the price of a MY 2025 passenger car by somewhat more than $300, while the corresponding difference for a MY 2025 light truck is relatively larger at a bit less than $1,500. If a 7 percent discount rate is applied, these values decline to under $200 for passenger cars and to under $900 for light trucks.

Table VIII-25
Value of Fuel Savings vs. Vehicle Price Increases
with Alternative Assumptions about Vehicle Buyer Time Horizons[389]

Vehicle	**Measure**	**Value Over Alternative Time Horizons (3% Discount Rate)**		
		Expected Lifetime	**10 Years**	**Average Loan Term**
MY 2025 Passenger Car	**Fuel Savings**	$4,695	$3,927	$2,277
	Price Increase	$1,926	$1,926	$1,926
	Difference	$2,769	$2,001	$351
MY 2025 Light Truck	**Fuel Savings**	$5,894	$4,733	$2,824
	Price Increase	$1,348	$1,348	$1,348
	Difference	$4,546	$3,385	$1,476

Vehicle	**Measure**	**Value Over Alternative Time Horizons (7% Discount Rate)**		
		Expected Lifetime	**10 Years**	**Average Loan Term**
MY 2025 Passenger Car	**Fuel Savings**	$3,874	$3,376	$2,109
	Price Increase	$1,926	$1,926	$1,926
	Difference	$1,948	$1,450	$183
MY 2025 Light Truck	**Fuel Savings**	$4,630	$3,718	$2,219
	Price Increase	$1,348	$1,348	$1,348
	Difference	$3,282	$2,370	$871

Potential vehicle buyers may also discount future fuel future savings using higher rates than those typically used to evaluate federal regulations. (For some consumers, these high discount rates might reflect rational behavior[390]; for others, they might reflect an excessive focus on the short-term and a neglect of the future.) OMB guidance prescribes that future benefits and costs of regulations that mainly affect private consumption decisions, as will be the case if manufacturers' costs for complying with higher fuel economy standards are passed on to vehicle buyers, should be discounted using a consumption rate of time preference.[391] OMB estimates

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[389] The average term on new-vehicle loans made by auto finance companies during 2010 was 63 months; see Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G. 19, Consumer Credit, http://www.federalreserve.gov/releases/g19/Current/ (last accessed October 9, 2011).

[390] For example, it may be rational for a consumer who drives very few miles per year [and expects this pattern to continue well into the future] to place little value on fuel savings, thereby implying a large discount rate.

[391] Office of Management and Budget, Circular A-4, "Regulatory Analysis," September 17, 2003, 33. Available at http://www.whitehouse.gov/sites/default/files/omb/assets/regulatory_matters_pdf/a-4.pdf (last accessed November 11, 2011) or Docket No. NHTSA-2010-0131.

that savers currently discount future consumption at an average real or inflation-adjusted 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. However, vehicle buyers may view the value of future fuel savings that results from purchasing a vehicle with higher fuel economy as risky or uncertain, or they may instead discount future consumption at rates reflecting their costs for financing the higher capital outlays required to purchase more fuel-efficient models. In either case, they may discount future fuel savings at rates other than the 3 and 7 percent levels assumed in NHTSA's evaluation.

Table VIII-26 shows the effect of alternative discount rates on vehicle buyers' evaluation of the fuel savings projected to result from the CAFE standards established by this rule, again using MY 2025 passenger cars and light trucks as an example. As Table VIII-25 showed, average future fuel savings discounted at the 3 percent consumer rate exceed the agency's estimated price increases by a somewhat less than $2,800 for MY 2025 passenger cars and by more than $4,500 for MY 2025 light trucks over the expected vehicle lifetime from the consumer perspective. If vehicle buyers instead discount future fuel savings at the average new-car loan rate (5.3%)[392], however, these differences decline to under $2,300 for cars and about $3,800 for light trucks, as Table VIII-26 illustrates. This is a particularly plausible alternative assumption, because buyers are likely to finance the increases in purchase prices resulting from compliance with higher CAFE standards as part of the process financing the vehicle purchase itself. Finally, as the table also shows, discounting future fuel savings using a consumer credit card rate (which averaged 13.8% during 2010)[393] reduces these differences to a over $900 for a MY 2025 passenger car and somewhat less than $1,600 for a MY 2025 light truck. Thus even at relatively high discount rates, the higher fuel economy levels required by this final rule would generate significant net benefits to vehicle buyers.

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[392] New car loan rates in the first quarter of 2011 averaged 5.86 percent at commercial banks and 4.73 percent at auto finance companies, for a combined average close to 5.3 percent.; see Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release G. 19, Consumer Credit, http://www.federalreserve.gov/releases/g19/Current/ (last accessed October 10, 2011).

[393] *Ibid.* The average interest rate on consumer credit card accounts at commercial banks was 13.78% during 2010.

Table VIII-26
Value of Lifetime[394] Fuel Savings vs. Vehicle Price Increases
with Alternative Assumptions about Consumer Discount Rates[395]

Vehicle	**Measure**	**Value at Alternative Discount Rates**			
		Consumer Rate (3%)	**New Car Loan Rate (5.3%)**	**Alternate Consumer Rate (7%)**	**Consumer Credit Card Rate (13.8%)**
MY 2025 Passenger Car	**Fuel Savings**	$4,695	$4,185	$3,874	$2,869
	Price Increase	$1,926	$1,926	$1,926	$1,926
	Difference	$2,769	$2,259	$1,948	$943
MY 2025 Light Truck	**Fuel Savings**	$5,894	$5,147	$4,630	$2,910
	Price Increase	$1,348	$1,348	$1,348	$1,348
	Difference	$4,546	$3,799	$3,282	$1,562

Combinations of a shorter time horizon and a higher discount rate could further reduce or even eliminate the difference between the value of fuel savings and the agency's estimates of increases in vehicle prices. One plausible combination would be for buyers to discount fuel savings over the term of a new car loan, using the interest rate on that loan as a discount rate. Assuming a 48-month loan at the previously stated rate of 5.3%, the outcomes differ between passenger cars and light trucks for MY 2025. For passenger cars, the typical consumer would see fuel savings outpace the vehicle price increase by $249 in this 48-month period. For consumers of light trucks, this difference amounts to $1,145 over the same 48-month period.

Some evidence suggests directly that vehicle buyers may employ combinations of higher discount rates and shorter time horizons than the agency assumes; for example, consumers surveyed by Kubik (2006) reported that fuel savings would have to be adequate to pay back the additional purchase price of a more fuel-efficient vehicle in less than 3 years to persuade a typical buyer to purchase it.[396] As these comparisons and evidence illustrate, reasonable alternative assumptions about how consumers might evaluate the major benefit from requiring higher fuel economy can significantly reduce its magnitude from the agency's estimate.

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[394] As in Table VII-25, in Table VIII-26 the lifetime of a vehicle is considered from the consumer perspective, with anticipated lifetimes of 14 years for passenger cars and 16 years for light trucks.

[395] The fuel-economy-improving technologies chosen within the CAFE model are to a small extent affected by the choice of the consumer discount rate applied to fuel savings. The CAFE model is run at 3 and 7 percent corresponding discount rates only. Analysis of the effect of alternate discount rates on the value of fuel savings is therefore slightly less precise to the extent that the CAFE model may have selected a different mix of technologies at the given alternate discount rate.

[396] Kubik, M. (2006). Consumer Views on Transportation and Energy. Second Edition. Technical Report: National Renewable Energy Laboratory. Available at http://www.nrel.gov/docs/fy05osti/36785.pdf or Docket No. NHTSA-2010-0131.

Imaginable combinations of shorter time horizons, higher discount rates, and lower expectations about future fuel prices or annual vehicle use and fuel savings could make potential buyers hesitant or even unwilling to purchase vehicles offering the fuel economy levels this rule will require. At the same time, they would also cause vehicle buyers' collective assessment of how the benefits from requiring higher fuel economy compare to the costs they will be required to pay for it to differ significantly from NHTSA's assessment of the aggregate benefits and costs of this rule. If consumers' views about critical variables such as future fuel prices or the appropriate discount rate differ sufficiently from the assumptions used by the agency, potential vehicle buyers might conclude that the value of fuel savings and other benefits they will experience from higher fuel economy are not sufficient to justify the increase in purchase prices they expect to pay.

Another possibility is that achieving the fuel economy improvements required by stricter fuel economy standards might lead manufacturers to forego planned future improvements in performance, carrying capacity, safety, or other features of their vehicle models that represent important sources of utility to vehicle owners. In extreme cases, manufacturers might even find it necessary to change the levels of these attributes that some currently available models offer. Although the specific economic values that vehicle buyers attach to individual vehicle attributes such as fuel economy, performance, passenger- and cargo-carrying capacity, and other sources of vehicles' utility are difficult to infer from their purchasing decisions and vehicle prices – as evidenced by significant variability in findings in economic literature on these topics – changes in vehicle attributes can significantly affect the overall utility that vehicles offer to potential buyers. Compromises in these or other highly-valued attributes would be viewed by potential buyers as an additional cost of improving fuel economy that the agency has failed to acknowledge or include in its estimates of the costs of complying with stricter CAFE standards.

As indicated in its previous discussion of technology costs, NHTSA has approached this potential problem by developing cost estimates for fuel economy-improving technologies that include allowances for any additional manufacturing costs that would be necessary to maintain the reference fleet (or baseline) levels of performance, comfort, capacity, or safety of light-duty vehicle models to which those technologies are applied. In doing so, the agency followed the precedent established by the 2011 NAS Report on improving fuel economy, which estimated "constant performance and utility" costs for technologies that manufacturers could employ to increase the fuel efficiency of cars or light trucks. Although NHTSA has revised its estimates of manufacturers' costs for some technologies significantly for use in this rulemaking, these revised estimates are still intended to represent costs that would allow manufacturers to maintain the performance, carrying capacity, and utility of vehicle models while improving their fuel economy.

The agency readily acknowledges the difficulty of estimating technology costs that include adequate provision for the accompanying changes in vehicle design that are necessary to maintain performance, capacity, and utility. While NHTSA believe that its cost estimates for fuel economy-improving technologies are sufficient to prevent significant compromises in other attributes of the vehicle models to which manufacturers apply them, it is possible that these costs do not include adequate allowance for the necessary investments by manufacturers to maintain baseline levels of these critical vehicle attributes. If this is the case, the true economic costs of achieving higher fuel economy would include the opportunity costs to vehicle owners of any sacrifices in vehicles' performance, carrying capacity, and utility that accompanied increases in their fuel economy. In that event, the agencies' estimated technology costs would underestimate the true economic costs of complying with stricter fuel economy emission standards.

Finally, it is possible that vehicle buyers may simply prefer the choices of vehicle models they now have available to the combinations of price, fuel economy, and other attributes that manufacturers are likely to offer when required to achieve higher overall fuel economy. If this is the case, their choices among models – and even some buyers' decisions about whether to purchase a new vehicle – will respond accordingly, and their responses to these new choices will reduce their overall welfare. Some may buy models with combinations of price, fuel efficiency, and other attributes that they consider less desirable than those they would otherwise have purchased, while others may simply postpone buying a new vehicle. It is also possible that manufacturers may discontinue some currently popular vehicle models or styles as part of their efforts to comply with requirements for higher fuel efficiency. Any losses in buyers' welfare associated with these responses are unlikely to be large enough to offset the estimated value of fuel savings reported in the agencies' analyses due to the sheer magnitude of the fuel savings resulting from the proposed standards; however, it is possible that buyers' welfare losses could significantly reduce the benefits from requiring manufacturers to achieve higher fuel efficiency, particularly in combination with the other possibilities outlined previously. (Recall, however, that NHTSA has attempted to respond to the potential problem by developing cost estimates that include allowances for any additional manufacturing expenses that would be necessary to maintain the reference fleet levels of performance, comfort, capacity, or safety of the light-duty vehicle models to which those technologies are applied.)

An entirely different explanation for buyers' reluctance to invest in higher fuel economy despite the large economic return it appears to promise is that the agency's assertion that the benefits buyers will experience from higher fuel economy far outweigh the costs they will pay to acquire it is indeed correct, yet certain plausible – if short-sighted – aspects of normal behavior nevertheless make buyers reluctant to purchase vehicles whose higher fuel economy offers an attractive return. For example, consumers' understandable aversion to the prospect of losses (the behavioral phenomenon of "loss aversion") from making investments that do not produce their expected returns may exaggerate their uncertainty about the value of future fuel savings sufficiently to make purchasing a more fuel-efficient vehicle seem unattractive even when doing so *is* likely to be a sound economic decision. Compare the finding in Greene et al. (2009), to the effect that the expected net present value of increasing the fuel economy of a passenger car from 28 to 35 miles per gallon falls from $405 when calculated using standard net present value calculations, to nearly zero when uncertainty regarding future cost savings is taken into account.[397]

Another possible reconciliation of the agency's claim that the *average* vehicle buyer will experience large fuel savings from the higher CAFE standards this rule establishes with the fact

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[397] Greene, D., J. German, and M. Delucchi (2009). "Fuel Economy: The Case for Market Failure" in Reducing Climate Impacts in the Transportation Sector, Sperling, D., and J. Cannon, eds. Springer Science. Surprisingly, the authors find that uncertainty regarding the future price of gasoline appears to be less important than uncertainty surrounding the expected lifetimes of new vehicles. Available at http://trid.trb.org/view.aspx?id=904190

that the *average* fuel economy of vehicles currently purchased falls well short of the new standards is that the values consumers place on the future savings they expect to obtain from higher fuel economy vary widely. As an illustration, one recent review of consumers' willingness to pay for improved fuel economy found estimates that varied from less than 1% to almost ten times the present value of the resulting fuel savings when those are discounted at 7% over the vehicle's expected lifetime.[398][399] Although the wide variation in these estimates partly undoubtedly reflects methodological and measurement differences among the studies surveyed, it probably also reflects the fact that the expected savings from purchasing a vehicle with higher fuel economy vary widely among individuals, because they travel different amounts, have different driving styles, or have different expectations about future fuel prices.

This is likely to be reflected in the fact that many buyers with high valuations of increased fuel economy *already* purchase vehicle models that offer it, while those with lower values of fuel economy emphasize other vehicle attributes in their purchasing decisions. A related possibility is that because the effects of differing fuel economy levels are relatively unimportant when compared to other, more prominent features of new vehicles – passenger and cargo-carrying capacity, performance, safety, etc. – it is simply not in many shoppers' interest to spend the time and effort necessary to determine the economic value of higher fuel economy, attempt to isolate the component of a new vehicle's selling price that is related to its fuel economy, and compare these two. (This may be so even though more fuel-efficient choices might ultimately be in consumers' economic self-interest.) In either case, although the agency's estimates of the *average* value of fuel savings that will result from requiring cars and light trucks to achieve higher fuel economy may be correct, it may not be large enough to lead a sufficient number of buyers to purchase vehicles with higher fuel economy to increase average fuel economy from its current levels.

Defects in the market for cars and light trucks could also lead manufacturers to undersupply fuel economy, even in cases where many (informed) buyers would be willing to pay the increased prices necessary to provide it. Most obviously, an absence of vigorous competition among producers of cars and light trucks may lead manufacturers to undersupply attributes that contribute to the overall quality of new vehicles, including fuel economy, because such "imperfect" competition reduces producers' profit incentive to supply the level of fuel economy that buyers are willing to pay for. Incomplete or "asymmetric" access to information on vehicle attributes such as fuel economy – whereby manufacturers of new vehicles or sellers of used cars and light trucks have more complete knowledge of vehicles' actual fuel economy levels, or of the value of purchasing higher fuel economy, than do potential buyers – may also prevent sellers of new or used vehicles from capturing its full value. In this situation, the level of fuel efficiency provided in the markets for new or used vehicles might remain persistently lower than that demanded by potential buyers.

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[398] Greene, David L., "How Consumers Value Fuel Economy: A Literature Review," Draft report to U.S. Environmental Protection Agency, Oak Ridge National Laboratory, March, 2010; see Table 10, p. 37. Available at http://www.epa.gov/otaq/climate/regulations/420r10008.pdf or Docket NHTSA-2010-0131

[399] Jin-Tan Liu (1988). "Automotive Fuel Economy Improvements and Consumers' Surplus." Transportation Research Part A 22A(3): 203-218 (Docket EPA-HQ-OAR-2009-0472-0045). The study actually calculated the willingness to pay for reduced vehicle operating costs, of which vehicle fuel economy is a major component.

It is also possible that deliberate decisions by manufacturers of cars and light trucks, rather than constraints on the combinations of fuel economy, carrying capacity, and performance that manufacturers can offer using current technologies, limit the range of fuel economy available to buyers within individual vehicle market segments, such as full-size automobiles, small SUVs, or minivans. As an illustration, once a potential buyer has decided to purchase a minivan, the range of fuel economy among current models extends only from 18 to 24 MPG.[400] Manufacturers might make such decisions if they underestimate the premiums that shoppers in certain market segments are willing to pay for more fuel-efficient versions of the vehicle models thy currently offer to prospective buyers within those segments. If this occurs, manufacturers may fail to supply levels of fuel efficiency as high as those buyers are willing to pay for, and the average fuel efficiency of their entire new vehicle fleets could remain below the levels that potential buyers demand and are willing to pay for.

Finally, some research suggests that the consumers' apparent unwillingness to purchase more fuel efficient vehicles stems from their inability to value future fuel savings correctly. For example, Larrick and Soll (2008) find evidence that consumers do not understand how to translate changes in fuel economy, which is denominated in miles per gallon, into resulting changes in fuel consumption, measured in gallons per time period.[401] Sanstad and Howarth (1994) argue that consumers appear optimize behavior without full information by resorting to imprecise but convenient rules of thumb, which can cause many buyers to underestimate the value of fuel savings, particularly from significant increases in fuel economy.[402] If the behavior identified in these studies is indeed widespread, then the agency's calculations suggesting that the benefits to vehicle owners from requiring higher fuel economy significantly exceeds the costs of providing it may indeed be correct, yet the resulting difference is still insufficient to lead the market to provide a mix of car or light truck vehicle models whose average fuel economy approaches those required by this rule.

The agency has been unable to reach a conclusive answer to the question of why the apparently large differences between its estimates of benefits from requiring higher fuel economy and the costs of supplying it do not result in higher average fuel economy for new cars and light trucks. One explanation is that NHTSA's estimates are reasonable, and the market for fuel economy is simply not operating efficiently. For reasons stated above, NHTSA believes that a number of imperfections in the relevant market (including the lack of salience of fuel economy benefits and an emphasis on the short-term) likely play a key role, thus justifying the conclusion that the private benefits are substantial. However, the agency acknowledges that this situation may also reflect the fact that some combination of overestimating the value of fuel savings and omitting potential reductions in the welfare of vehicle buyers means that it has not fully characterized the impact of the CAFE standards this rule establishes on consumers. To recognize this possibility,

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[400] This is the range of combined city and highway fuel economy levels from lowest (Toyota Siena 4WD) to highest (Mazda 5) available for model year 2010; http://www.fueleconomy.gov/feg/bestworstEPAtrucks.htm (last accessed February 15, 2010).

[401] Larrick, R. P., and J.B. Soll (2008). "The MPG illusion." *Science* 320: 1593-1594. Available at http://www.sciencemag.org/content/320/5883/1593.full?ijkey=3pScQm7pQBzqs&keytype=ref&siteid=sci (last accessed November 14, 2011) or Docket No. NHTSA-2011-0131

[402] Sanstad, A., and R. Howarth (1994). "'Normal' Markets, Market Imperfections, and Energy Efficiency." Energy Policy 22(10): 811-818. Available at http://www.sciencedirect.com/science/article/B6V2W-48XK8TT-K/2/1a97627ce2ed92b2aaa7b600bafa0e79 (last accessed November 14, 2011)

and as part of a sensitivity analysis, this section presents an alternative accounting of the benefits and costs of CAFE standards for MY 2017-2025 passenger cars and light trucks and discusses its implications.

Table VIII-27 displays the economic impacts of the rule from the perspective of potential buyers, and also reconciles the estimated net benefits of the rule as they are likely to be viewed by vehicle buyers with its net benefits to the economy as a whole. As the table shows, the total benefits to vehicle buyers (line 4) consist of the value of fuel savings at retail fuel prices (line 1), the economic value of vehicle occupants' savings in refueling time (line 2), and the economic benefits from added rebound-effect driving (line 3). As the zero entries in line 5 of the table suggest, the agency's estimate of the retail value of fuel savings reported in line 1 is assumed to be correct, and no losses in consumer welfare from changes in vehicle attributes (other than those from increases in vehicle prices) are assumed to occur. Thus there is no reduction in the total private benefits to vehicle owners, so that net private benefits to vehicle buyers (line 6) are equal to total private benefits (reported previously in line 4).

As Tables VIII-27 and VIII-28 (presented at 3 and 7 percent discount rates, respectively) also show, the decline in fuel tax revenues (line 7) that results from reduced fuel purchases is in effect an external cost from the viewpoint of vehicle buyers, which offsets part of the benefits of fuel savings when those are viewed from the economy-wide or "social" perspective.[403] Thus the sum of lines 1 and 7 is the savings in fuel production costs that was reported previously as the value of fuel savings at pre-tax prices in the agency's usual accounting of benefits and costs (see Chapter X). Lines 8 and 9 of Tables VIII-27 and VIII-28 report the value of reductions in air pollution and climate-related externalities resulting from lower emissions during fuel production and consumption, while line 10 reports the savings in petroleum market externalities to the U.S. economy from reduced production of crude petroleum and refined fuel. Line 12 reports the costs of increased congestion delays, accidents, and noise that result from additional driving due to the fuel economy rebound effect; net social benefits (line 13) is thus the sum of the change in fuel tax revenues, the reduction in environmental and petroleum market externalities, and increased costs from added driving.

Line 14 in both Table VIII-27 and Table VIII-28 shows manufacturers' technology outlays for meeting higher CAFE standards for passenger cars and light trucks, which represent the principal cost of requiring higher fuel economy. The net total benefits (line 15) resulting from the rule consist of the sum of private (line 6) and social (line 13) benefits, minus technology costs (line 14); as expected, the figures reported in line 15 are identical to those reported in the agency's customary format (see Chapter X).

Tables VIII-27 and VIII-28 highlight several important features of this rule's economic impacts. First, comparing the rule's net private (line 6) and external (line 13) benefits makes it clear that a

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[403] Strictly speaking, fuel taxes represent a transfer of resources from consumers of fuel to government agencies and not a use of economic resources. Reducing the volume of fuel purchases simply reduces the value of this transfer, and thus cannot produce a real economic cost or benefit. Representing the change in fuel tax revenues in effect as an economy-wide cost is necessary to offset the portion of fuel savings included in line 1 that represents savings in fuel tax payments by consumers. This prevents the savings in tax revenues from being counted as a benefit from the economy-wide perspective.

substantial majority of the benefits from requiring higher fuel economy are experienced by vehicle buyers, with only a small share distributed throughout the remainder of the U.S. economy. In turn, the vast majority of private benefits stem from fuel savings, which highlights the importance of the many assumptions the agency uses to estimate and value future fuel savings resulting from higher fuel economy, as well as of the assumption that the rule has no adverse impacts on vehicle buyers. The aggregate external benefits are small compared to total technology costs.

As a consequence, the net economic benefits of the rule closely mirror the benefits to private vehicle buyers and the technology costs for achieving higher fuel economy, again highlighting the importance of correctly valuing fuel savings from the perspective of those who experience them and accounting for any other effects of the rule on the economic welfare of vehicle buyers.

Table VIII-27a
Private, Social, and Total Benefits and Costs of MY 2017 – 2025 CAFE Standards
Passenger Cars and Light Trucks Combined
in Billions of 2009$
(3% Discount Rate)

Entry	Model Year				
	2017	**2018**	**2019**	**2020**	**2021**
1) Value of Fuel Savings (at Retail Fuel Prices)	$7.9	$17.1	$30.6	$41.7	$54.0
2) Savings in Refueling Time	$0.4	$0.7	$1.2	$1.6	$1.8
3) Consumer Surplus in Additional Driving	$0.1	$0.2	$0.4	$0.6	$0.9
4) Total Private Benefits (=1+2+3)	$8.4	$18.0	$32.1	$44.0	$56.7
5) Reduction in Private Benefits	$0.0	$0.0	$0.0	$0.0	$0.0
6) Net Private Benefits (=4+5)	$8.4	$18.0	$32.1	$44.0	$56.7
7) Change in Fuel Tax Revenues	($0.9)	($1.8)	($3.2)	($4.4)	($5.5)
8) Reduced Health Damages from Criteria Emissions	$0.2	$0.5	$0.9	$1.2	$1.6
9) Reduced Climate Damages from CO2 Emissions	$0.7	$1.6	$2.9	$4.0	$5.2
10) Reduced Petroleum Market Externalities	$0.4	$0.8	$1.4	$2.0	$2.5
11) Reduction in Externalities (=8+9+10)	$1.4	$2.9	$5.2	$7.2	$9.4
12) Increased Costs of Congestion, etc.	($0.8)	($1.7)	($3.1)	($4.1)	($5.2)
13) Net Social Benefits =(7+11+12)	($0.3)	($0.6)	($1.1)	($1.2)	($1.4)
14) Technology Costs	($1.7)	($4.2)	($7.3)	($10.8)	($14.6)
15) Net Total Benefits (6+12+14)	$6.3	$13.3	$23.8	$31.9	$40.7

Table VIII-27b
Private, Social, and Total Benefits and Costs of MY 2017 – 2025 CAFE Standards
Passenger Cars and Light Trucks Combined
in Billions of 2009$
(3% Discount Rate)

Entry	**Model Year**				
	2022	**2023**	**2024**	**2025**	**9-Yr Total**
1) Value of Fuel Savings (at Retail Fuel Prices)	$61.8	$71.5	$82.9	$96.0	$463.6
2) Savings in Refueling Time	$2.1	$2.3	$2.7	$2.6	$15.3
3) Consumer Surplus in Additional Driving	$1.1	$1.4	$1.9	$2.6	$9.1
4) Total Private Benefits (=1+2+3)	$64.9	$75.2	$87.4	$101.2	$488.0
5) Reduction in Private Benefits	$0.0	$0.0	$0.0	$0.0	$0.0
6) Net Private Benefits (=4+5)	$64.9	$75.2	$87.4	$101.2	$488.0
7) Change in Fuel Tax Revenues	($6.3)	($7.2)	($8.3)	($9.6)	($47.2)
8) Reduced Health Damages from Criteria Emissions	$1.8	$2.1	$2.4	$2.5	$13.3
9) Reduced Climate Damages from CO2 Emissions	$6.1	$7.1	$8.3	$9.7	$45.6
10) Reduced Petroleum Market Externalities	$2.9	$3.3	$3.8	$4.4	$21.5
11) Reduction in Externalities (=8+9+10)	$10.8	$12.5	$14.5	$16.7	$80.5
12) Increased Costs of Congestion, etc.	($5.9)	($6.9)	($8.0)	($9.3)	($44.8)
13) Net Social Benefits =(7+11+12)	($1.4)	($1.6)	($1.7)	($2.2)	($11.6)
14) Technology Costs	($17.0)	($21.2)	($25.5)	($29.9)	($132.1)
15) Net Total Benefits (6+12+14)	$46.5	$52.4	$60.3	$69.1	$344.3

Table VIII-28a
Private, Social, and Total Benefits and Costs of MY 2017 – 2025 CAFE Standards
Passenger Cars and Light Trucks Combined
in Billions of 2009$
(7% Discount Rate)

Entry	**Model Year**				
	2017	**2018**	**2019**	**2020**	**2021**
1) Value of Fuel Savings (at Retail Fuel Prices)	$6.3	$13.6	$24.2	$33.1	$42.8
2) Savings in Refueling Time	$0.3	$0.6	$0.9	$1.3	$1.5
3) Consumer Surplus in Additional Driving	$0.0	$0.1	$0.3	$0.5	$0.7
4) Total Private Benefits (=1+2+3)	$6.7	$14.3	$25.5	$34.9	$45.0
5) Reduction in Private Benefits	$0.0	$0.0	$0.0	$0.0	$0.0
6) Net Private Benefits (=4+5)	$6.7	$14.3	$25.5	$34.9	$45.0
7) Change in Fuel Tax Revenues	($0.7)	($1.5)	($2.6)	($3.5)	($4.5)
8) Reduced Health Damages from Criteria Emissions	$0.2	$0.4	$0.7	$1.0	$1.3
9) Reduced Climate Damages from CO2 Emissions	$0.7	$1.6	$2.9	$4.0	$5.2
10) Reduced Petroleum Market Externalities	$0.3	$0.6	$1.1	$1.6	$2.0
11) Reduction in Externalities (=8+9+10)	$1.2	$2.7	$4.8	$6.6	$8.5
12) Increased Costs of Congestion, etc.	($0.6)	($1.3)	($2.5)	($3.2)	($4.2)
13) Net Social Benefits =(7+11+12)	($0.1)	($0.1)	($0.3)	($0.2)	($0.1)
14) Technology Costs	($1.7)	($4.2)	($7.3)	($10.8)	($14.6)
15) Net Total Benefits (6+12+14)	$4.8	$10.0	$17.9	$23.9	$30.3

Table VIII-28b
Private, Social, and Total Benefits and Costs of MY 2017 – 2025 CAFE Standards
Passenger Cars and Light Trucks Combined
in Billions of 2009$
(7% Discount Rate)

Entry	**Model Year**				
	2022	**2023**	**2024**	**2025**	**9-Yr Total**
1) Value of Fuel Savings (at Retail Fuel Prices)	$49.1	$56.8	$66.0	$76.5	$368.4
2) Savings in Refueling Time	$1.7	$1.8	$2.1	$2.1	$12.2
3) Consumer Surplus in Additional Driving	$0.8	$1.2	$1.5	$2.1	$7.2
4) Total Private Benefits (=1+2+3)	$51.6	$59.8	$69.6	$80.6	$387.8
5) Reduction in Private Benefits	$0.0	$0.0	$0.0	$0.0	$0.0
6) Net Private Benefits (=4+5)	$51.6	$59.8	$69.6	$80.6	$387.8
7) Change in Fuel Tax Revenues	($5.0)	($5.8)	($6.7)	($7.7)	($37.9)
8) Reduced Health Damages from Criteria Emissions	$1.5	$1.7	$1.9	$2.0	$10.7
9) Reduced Climate Damages from CO2 Emissions	$6.1	$7.1	$8.3	$9.7	$45.6
10) Reduced Petroleum Market Externalities	$2.3	$2.6	$3.0	$3.6	$17.2
11) Reduction in Externalities (=8+9+10)	$9.8	$11.4	$13.3	$15.3	$73.5
12) Increased Costs of Congestion, etc.	($4.7)	($5.5)	($6.4)	($7.5)	($35.8)
13) Net Social Benefits =(7+11+12)	$0.1	$0.1	$0.3	$0.1	($0.2)
14) Technology Costs	($17.0)	($21.2)	($25.5)	($29.9)	($132.1)
15) Net Total Benefits (6+12+14)	$34.6	$38.7	$44.4	$50.8	$255.5

As discussed in detail previously, it is possible that NHTSA has over or underestimated the value of fuel savings to buyers and subsequent owners of the cars and light trucks to which higher CAFE standards will apply. It is also possible that the agency has failed to identify and value reductions in consumer welfare that could result from buyers' responses to higher vehicle prices or changes in vehicle attributes that manufacturers make as part of their efforts to achieve higher fuel economy. To acknowledge these possibilities and examine their potential impact on the rule's benefits and costs, and in order to provide a sensitivity analysis, Tables VIII-29 and VIII-30 show the rule's cumulative economic impacts by model year for MY 2017-2025 passenger cars and light trucks under varying assumptions about the agency's potential mis-estimation of fuel savings and the value of potential changes in vehicle attributes such as performance, carrying capacity, or safety.

Tables VIII-29 and VIII-30 provide examples of effects of *both* potential overestimation of the value of fuel savings to vehicle buyers and the possible omission of welfare losses from changes in other vehicle attributes in the entry labeled “Reduction in Private Benefits” (line 5). Although the examples reported previously in Tables VIII-25 and VIII-26 illustrated sources of possible overestimation of fuel savings using specific alternatives to the agency’s assumptions, NHTSA has been unable to determine exactly how buyers’ time horizons or discount rates might differ from those assumed in its analysis. Nor has NHTSA analyzed how vehicle buyers’ expectations about future fuel prices or differences between fuel economy ratings and actual on-road fuel economy might differ from those it employs to estimate the value of fuel savings. Finally, NHTSA has not attempted to project changes in vehicle attributes other than fuel economy, or to estimate the economic value of resulting losses in vehicle utility.

Instead Tables VIII-29 and VIII-30 illustrate, at 3 and 7 percent discount rates, respectively, the effect of these possibilities using different assumptions about the fraction of total private benefits to vehicle buyers that might be offset by some combination of these factors. It is important to see that these assumptions are used merely for the sake of analysis and illustration; there is no claim here that they have an empirical basis, or that they are founded in any existing estimates, theoretical or empirical, of actual offsets.[404] As Tables VIII-29 and VIII-30 show, if there is no offset to private benefits, the rule’s total and net private and social benefits are exactly as shown in the last column of the corresponding table (Table VIII-27 or VIII-28) above. If, however, these factors combine to offset as much as 25% of the agency’s estimate of total private benefits (line 5), the rule’s net private (line 6) and net total (line 15) benefits remain substantially positive. If the private savings turn out to be 25% less than projected, the benefits of the rule continue to justify the costs by a large measure. If the offset is assumed to be as much as 50%, the net total benefits (line 15) would significantly decline, but would remain positive, and the benefits would continue to justify the costs by a large measure.

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[404] While some empirical evidence suggests that consumers are largely making rational decisions, other evidence suggests this is not the case. Since there is not agreement in the literature on this point, it is not possible to estimate the potential degree of consumer loss in welfare.

Table VIII-29
Effect of Overestimation of Fuel Savings or Omission of Welfare Losses on Net Private and Total Benefits of MY 2017-2025 CAFE Standard
Passenger Cars and Light Trucks Combined
in Billions of 2009$
(3% Discount Rate)

Entry	**Fraction of Private Benefits Offset by Overestimation of Fuel Savings or Omission of Welfare Losses to Vehicle Buyers**		
	None	**25%**	**50%**
1) Value of Fuel Savings (at Retail Fuel Prices)	$463.6	$463.6	$463.6
2) Savings in Refueling Time	$15.3	$15.3	$15.3
3) Consumer Surplus in Additional Driving	$9.1	$9.1	$9.1
4) Total Private Benefits (=1+2+3)	$488.0	$488.0	$488.0
5) Reduction in Private Benefits	$0.0	$122.0	$244.0
6) Net Private Benefits (=4+5)	$488.0	$366.0	$244.0
7) Change in Fuel Tax Revenues	($47.2)	($47.2)	($47.2)
8) Reduced Health Damages from Criteria Emissions	$13.3	$13.3	$13.3
9) Reduced Climate Damages from CO2 Emissions	$45.6	$45.6	$45.6
10) Reduced Petroleum Market Externalities	$21.5	$21.5	$21.5
11) Reduction in Externalities (=8+9+10)	$80.5	$80.5	$80.5
12) Increased Costs of Congestion, etc.	($44.8)	($44.8)	($44.8)
13) Net Social Benefits =(7+11+12)	($11.6)	($11.6)	($11.6)
14) Technology Costs	($132.1)	($132.1)	($132.1)
15) Net Total Benefits (6+12+14)	$344.3	$189.0	$67.0

Table VIII-30
Effect of Overestimation of Fuel Savings or Omission of Welfare Losses on Net Private and Total Benefits of MY 2017-2025 CAFE Standard
Passenger Cars and Light Trucks Combined
in Billions of 2009$
(7% Discount Rate)

Entry	**Fraction of Private Benefits Offset by Overestimation of Fuel Savings or Omission of Welfare Losses to Vehicle Buyers**		
	None	**25%**	**50%**
1) Value of Fuel Savings (at Retail Fuel Prices)	$368.4	$368.4	$368.4
2) Savings in Refueling Time	$12.2	$12.2	$12.2
3) Consumer Surplus in Additional Driving	$7.2	$7.2	$7.2
4) Total Private Benefits (=1+2+3)	$387.8	$387.8	$387.8
5) Reduction in Private Benefits	$0.0	$97.0	$193.9
6) Net Private Benefits (=4+5)	$387.8	$290.9	$193.9
7) Change in Fuel Tax Revenues	($37.9)	($37.9)	($37.9)
8) Reduced Health Damages from Criteria Emissions	$10.7	$10.7	$10.7
9) Reduced Climate Damages from CO2 Emissions	$45.6	$45.6	$45.6
10) Reduced Petroleum Market Externalities	$17.2	$17.2	$17.2
11) Reduction in Externalities (=8+9+10)	$73.5	$73.5	$73.5
12) Increased Costs of Congestion, etc.	($35.8)	($35.8)	($35.8)
13) Net Social Benefits =(7+11+12)	($0.2)	($0.2)	($0.2)
14) Technology Costs	($132.1)	($132.1)	($132.1)
15) Net Total Benefits (6+12+14)	$255.5	$122.9	$25.9

It is important to reemphasize that NHTSA views the estimates of this rule's economic impacts presented in Tables VIII-29 and VIII-30 as illustrative only. The agency has attempted to develop the most accurate estimates of the value of fuel savings that are possible. The design of the CAFE standards (*e.g.*, the footprint curves), the stringency of the standards, and the lead time provided to manufacturers for complying with the new standards have all been tailored to ensure that desirable vehicle attributes other than fuel economy will not be compromised. NHTSA has also attempted to ensure that its estimates of technology costs include adequate provisions to prevent the degradation of performance, safety, or other valuable attributes as consequences of manufacturers' efforts to comply with higher CAFE standards.

A major lesson is that the benefits of the rule justify the costs even on the assumption that the private savings are significantly offset (an assumption that the agency believes that to be to be highly unlikely). Nevertheless, the agency believes that it is important to acknowledge a degree of uncertainty in its estimates of how buyers are likely to value fuel savings, as well as in its conclusion that no losses in the performance, utility, or safety of cars and light trucks subject to this rule will occur. One conclusion is that even if the private savings are significantly overstated, the benefits of the proposed rules continue to exceed the costs. We seek comment on that analysis and the discussion above. NHTSA is committed to developing improved methods for estimating the value of improvements in fuel economy, as well as the magnitude and economic consequences of accompanying changes in other vehicle attributes, as part of its future CAFE rulemaking activities.

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IX. IMPACT OF WEIGHT REDUCTION ON SAFETY

In addition to the intended impacts of the final standards, like reduced fuel consumption and GHG emissions, the agencies recognize that there may be other impacts that are not intended. Among those impacts is the potential for safety trade-offs, which the agencies have assessed in evaluating the appropriate levels at which to set the proposed standards.
Mass reduction while holding a vehicle's footprint (size) constant is a potential strategy for meeting footprint-based CAFE and GHG standards. Basing standards on vehicle footprint ideally helps to discourage vehicle manufacturers from downsizing their vehicles, because the agencies set higher (more stringent) mpg targets for smaller-footprint vehicles, but would not similarly discourage mass reduction that maintains footprint while potentially improving fuel economy. Several technologies, such as substitution of light, high-strength materials for conventional materials during vehicle redesigns, have the potential to reduce weight and conserve fuel while maintaining a vehicle's footprint and maintaining or possibly improving the vehicle's structural strength and handling.

The relationship between a vehicle's mass, size, and fatality risk is complex, and it varies in different types of crashes. NHTSA, along with others, has been examining this relationship for over a decade. The safety chapter of NHTSA's April 2010 final regulatory impact analysis (FRIA) of CAFE standards for MY 2012-2016 passenger cars and light trucks included a statistical analysis of relationships between fatality risk, mass, and footprint in MY 1991-1999 passenger cars and LTVs (light trucks and vans), based on calendar year (CY) 1995-2000 crash and vehicle-registration data.[405]

The principal findings and conclusions of NHTSA's 2010 report were that mass reduction in the lighter cars, even while holding footprint constant would significantly increase fatality risk, whereas mass reduction in the heavier LTVs would significantly reduce societal fatality risk, because it would reduce the fatality risk of occupants of lighter vehicles colliding with those heavier LTVs. NHTSA concluded that, as a result, any *reasonable* combination of mass reductions that held footprint constant in MY 2012-2016 vehicles – concentrated, at least to some extent, in the heavier LTVs and limited in the lighter cars – would likely be approximately safety-neutral; it would not significantly increase fatalities and might well decrease them.

NHTSA's 2010 report partially agreed and partially disagreed with analyses published during 2003-2005 by Dynamic Research, Inc. (DRI). NHTSA and DRI both found a significant protective effect for footprint and that reducing mass and footprint together (downsizing) on smaller vehicles was harmful. On the other hand, DRI's analyses estimated significant overall benefits for mass reduction in all passenger cars and LTVs if wheelbase and track width were maintained, whereas NHTSA's report showed an overall benefit only in the heavier LTVs, but for other classes of vehicles, benefits only in some types of crashes. Much of NHTSA's 2010

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[405] Kahane, C. J. (2010). "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 1991-1999 and Other Passenger Cars and LTVs," *Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2012-MY 2016 Passenger Cars and Light Trucks*. Washington, DC: National Highway Traffic Safety Administration, pp. 464-542, available at http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/CAFE_2012-2016_FRIA_04012010.pdf. (last accessed November 11, 2011)

report as well as recent work by DRI involved sensitivity tests on the databases and models and generated a range of estimates somewhere between the initial DRI and NHTSA results.[406]

The previous databases of MY 1991-1999 vehicles in CY 1995-2000 crashes have become outdated as new safety technologies, vehicle designs and materials were introduced. The new databases comprising MY 2000-2007 vehicles in CY 2002-2008 crashes are the most up-to-date possible, given the processing time for crash data and the need for enough crash cases to permit statistically meaningful analyses. NHTSA has made the new databases available to the public at http://www.nhtsa.gov/fuel-economy, enabling other researchers to analyze the same data and hopefully minimizing discrepancies in the results that would have been due to inconsistencies across databases.[407]

One way to estimate these effects is statistical analyses of societal fatality rates per VMT, by vehicles' mass and footprint, for the current on-road vehicle fleet. The basic analysis method is the same as in NHTSA's 2010 report: cross-sectional analyses of the societal fatality rate per billion vehicle miles of travel (VMT) by mass and footprint, while controlling for driver age, gender, and other factors, in separate logistic regressions by vehicle class and crash type. Societal fatality rates include occupants of all vehicles in the crash as well as pedestrians. NHTSA's 2011 Report[408] analyzes MY 2000-2007 cars and LTVs in CY 2002-2008 crashes. Fatality rates were derived from FARS data, 13 State crash files, and registration and mileage data from R.L. Polk.

The most noticeable change in MY 2000-2007 vehicles from MY 1991-1999 has been the increase in crossover utility vehicles (CUV), which are SUVs of unibody construction, often but not always built upon a platform shared with passenger cars. CUVs have blurred the distinction between cars and trucks. The new analysis treats CUVs and minivans as a separate vehicle class, because they differ in some respects from pickup-truck-based LTVs and in other respects from passenger cars. In the 2010 reports, the many different types of LTVs were combined in a single analysis and NHTSA believes that this may have made the analyses too complex and might have contributed to some of the uncertainty in the results.

The new data has accurate VMT estimates, derived from a file of odometer readings by make, model, and model year recently developed by R.L. Polk and purchased by NHTSA.[409] For the

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[406] Van Auken, R. M., and Zellner, J. W. (2003). *A Further Assessment of the Effects of Vehicle Weight and Size Parameters on Fatality Risk in Model Year 1985-98 Passenger Cars and 1986-97 Light Trucks*. Report No. DRI-TR-03-01. Torrance, CA: Dynamic Research, Inc.; Van Auken, R. M., and Zellner, J. W. (2005a). *An Assessment of the Effects of Vehicle Weight and Size on Fatality Risk in 1985 to 1998 Model Year Passenger Cars and 1985 to 1997 Model Year Light Trucks and Vans*. Paper No. 2005-01-1354. Warrendale, PA: Society of Automotive Engineers; Van Auken, R. M., and Zellner, J. W. (2005b). *Supplemental Results on the Independent Effects of Curb Weight, Wheelbase, and Track on Fatality Risk in 1985-1998 Model Year Passenger Cars and 1986-97 Model Year LTVs*. Report No. DRI-TR-05-01. Torrance, CA: Dynamic Research, Inc.; Van Auken, R.M., and Zellner, J. W. (2011). "Updated Analysis of the Effects of Passenger Vehicle Size and Weight on Safety," *NHTSA Workshop on Vehicle Mass-Size-Safety*, Washington, February 25, 2011, http://www.nhtsa.gov/staticfiles/rulemaking/pdf/MSS/MSSworkshop_VanAuken.pdf

[407] 75 Fed. Reg. 25324 (May 7, 2010); the discussion of planned statistical analyses is on pp. 25395-25396.

[408] Kahane, C. J. (2011). "Relationships Between Fatality Risk, Mass, and Footprint in Model Year 2000-2007 Passenger Cars and LTVs", July 2011. Docket No. NHTSA-2010-0131

[409] In the 1991-1999 data base, VMT was estimated only by vehicle class, based on NASS CDS data.

2011 report, the relative distribution of crash types has been changed based on the effectiveness of electronic stability control (ESC). For example, the percent of rollover crashes has been reduced and two vehicle crashes increased. The total target population of fatalities was not decreased in the 2011 report, but is taken into account later in this analysis, since all vehicles in the future will be equipped with ESC.

For the 2011 report, vehicles are now grouped into five classes rather than four: passenger cars (including both 2-door and 4-door cars) are split in half by median weight; CUVs and minivans; and truck-based LTVs, which are also split in half by median weight of the model year 2000-2007 vehicles. Table IX-1 presents the estimated percent increase in societal fatality rates per 100-pound mass reduction while holding footprint constant for five classes of vehicles.

Table IX-1
Results of 2011 NHTSA report
Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant

MY 2000-2007 CY 2002-2008	Fatality Increase (%) Per 100-Pound Mass Reduction While Holding Footprint Constant	
	Point Estimate	95% Confidence Bounds
Cars < 3,106 pounds	**1.44**	+ .29 to +2.59
Cars ≥ 3,106 pounds	.47	- .58 to +1.52
CUVs and minivans	- .46	-1.75 to + .83
Truck-based LTVs < 4,594 pounds	.52	- .43 to +1.46
Truck-based LTVs ≥ 4,594 pounds	- .39	-1.06 to + .27

Only the 1.44 percent risk increase in the lighter cars is statistically significant. There are non-significant increases in the heavier cars and the lighter truck-based LTVs and non-significant societal benefits for mass reduction in CUVs, minivans, and the heavier truck-based LTVs. Based on these results, potential combinations of mass reductions that maintain footprint and are proportionately somewhat higher for the heavier vehicles may be safety-neutral or better as point estimates and, in any case, unlikely to significantly increase fatalities. The primarily non-significant results are not due to a paucity of data, but because the societal effect of mass reduction while maintaining footprint, if any, is small.

MY 2000-2007 vehicles of all types are heavier and larger than their MY 1991-1999 counterparts. The average mass of passenger cars increased by 5 percent from 2000 to 2007 and the average mass of pickup trucks increased by 19 percent. Other types of vehicles became heavier, on the average, by intermediate amounts. There are several reasons for these increases: during this time frame, some of the lighter make-models were discontinued; many models were redesigned to be heavier and larger; and consumers more often selected stretched versions such as crew cabs in their new-vehicle purchases.

It is interesting to compare the new results to NHTSA’s 2010 analysis of MY 1991-1999 vehicles in CY 1995-2000, especially the new point estimate to the “actual regression result scenario” in the 2010 report:

Table IX-2
2010 Report: MY 1991-1999, CY 1995-2000
Fatality Increase (%) per 100-Pound Mass Reduction While Holding Footprint Constant

	Actual Regression Result Scenario	Upper-Estimate Scenario	Lower-Estimate Scenario
Cars < 2,950 pounds	2.21	2.21	1.02
Cars ≥ 2,950 pounds	0.90	0.90	0.44
LTVs < 3,870 pounds	0.17	0.55	0.41
LTVs ≥ 3,870 pounds	-1.90	-0.62	-0.73

The new results are directionally the same as in 2010: fatality increase in the lighter cars, safety benefit in the heavier LTVs. But the effects may have become weaker at both ends. (The agency does not consider this conclusion to be definitive because of the relatively wide confidence bounds of the estimates.) The fatality increase in the lighter cars tapered off from 2.21 percent to 1.44 percent while the societal benefit of mass reduction in the heaviest LTVs diminished from 1.90 percent to 0.39 percent and is no longer statistically significant.

NHTSA believes that the changes may be due to a combination of “real” factors (characteristics of the newer vehicles) and revisions to the analysis. Above all, many cars with poor safety performance, which were often light, small cars, were discontinued by 2000 or during 2000-2007. The tendency of light, small vehicles to be driven poorly, while still there, is not as strong as it used to be – perhaps in part because safety improvements in lighter and smaller vehicles have made some good drivers more willing to buy them. At the other end of the spectrum, blocker beams and other voluntary compatibility improvements in LTVs as well as compatibility-related self-protection improvements to cars have made the heavier LTVs somewhat less aggressive in collisions with lighter vehicles (although the effect of mass disparity remains). This report’s analysis of CUVs and minivans as a separate class of vehicles may have relieved some inaccuracies in the 2010 regression results for LTVs. Interestingly, the new actual-regression results are quite close to the previous report’s “lower-estimate scenario,” which was an attempt to adjust for supposed inaccuracies in some regressions and for a seemingly excessive trend toward higher crash rates in smaller and lighter cars.

The principal difference between the heavier vehicles, especially truck-based LTVs, and the lighter vehicles, especially passenger cars, is that mass reduction has a different effect in collisions with another car or LTV. When two vehicles of unequal mass collide, the delta V is higher in the lighter vehicle, in the same proportion as the mass ratio. As a result, the fatality risk is also higher. Removing some mass from the heavy vehicle reduces delta V in the lighter vehicle, where fatality risk is high, resulting in a large benefit, offset by a small penalty because delta V increases in the heavy vehicle, where fatality risk is low – adding up to a net societal benefit. Removing some mass from the lighter vehicle results in a large penalty offset by a small benefit – adding up to net harm. <u>These considerations drive the overall result</u>: fatality increase in the lighter cars, reduction in the heavier LTVs, and little effect in the intermediate groups. However, in some types of crashes that do not involve collisions between cars and LTVs, especially 1st-event rollovers and impacts with fixed objects, mass reduction is usually not harmful and often beneficial, because the lighter vehicles respond more quickly to braking and steering and are often more stable because their center of gravity is lower. Offsetting that benefit is the continuing historical tendency of lighter and smaller vehicles to be driven less well – although it continues to be unknown why that is so, and to what extent, if any, the lightness or smallness of the vehicle contributes to people driving it less safely.

The estimates of the model are formulated for 100-pound mass reductions. What would be the effect of reducing mass by, say, 200 or 300 pounds? According to the model, if risk increases by 1 percent for 100 pounds, it would increase by 2 percent for 200 pounds and 3 percent for 300 pounds (more exactly, 2.01 percent and 3.03 percent, because the effects work like compound interest). Confidence bounds will grow wider by the same proportions.

For how many hundreds of pounds of mass reduction can the model predict accurately? This is the most difficult question. The model is best suited to predict the effect of a small change in mass, leaving everything else as it was when the model was developed (MY 2000-2007 in CY 2002-2008). With each additional change from the current environment, the model may become somewhat less accurate. The environment in 2017-2025 is bound to differ from 2000-2007. Nevertheless, one consideration provides some basis for confidence. This is NHTSA's fourth evaluation of the effects of mass reduction and/or downsizing, comprising databases ranging from MY 1985 to 2007. The results of the four studies are not identical, but they have been consistent up to a point. One of the most popular models of small 4-door sedans increased in curb weight from 1,939 pounds in MY 1985 to 2,766 pounds in MY 2007, a 43 percent increase. A high-sales mid-size sedan grew from 2,385 to 3,354 pounds (41%); a best-selling pickup truck from 3,390 to 4,742 pounds (40%) in the basic model with 2-door cab and rear-wheel drive; and a popular minivan from 2,940 to 3,862 pounds (31%). If the statistical analysis has, over the past years, been able to accommodate these gains on the order of 31-43 percent, perhaps it will also succeed in modeling the effects of mass reductions on the order of 10-20 percent, if they occur in the future.

Calculation of MY 2017-2025 safety impact

Neither the CAFE standards nor our analysis mandates mass reduction, or mandates that mass reduction occur in any specific manner. However, mass reduction is one of the technology applications available to the manufacturers and a degree of mass reduction is used by the Volpe model to determine the capabilities of manufacturers and to predict both cost and fuel consumption impacts of improved CAFE standards.

The agency utilized the relationships between weight and safety from Kahane (2011), expressed as percentage increases in fatalities per 100-pound weight reduction, and examined the weight impacts assumed in this CAFE analysis. However, there are several identifiable safety trends already in place or expected to occur in the foreseeable future that are not accounted for in the study. For example, there are two important new safety standards that have already been issued and will be phasing in after MY 2008. Federal Motor Vehicle Safety Standard No. 126 (49 CFR § 571.126) will require electronic stability control in all new vehicles by MY 2012, and the upgrade to Federal Motor Vehicle Safety Standard No. 214 (Side Impact Protection, 49 CFR § 571.214) will likely result in all new vehicles being equipped with head-curtain air bags by MY

2014. Additionally, we anticipate continued improvements in driver (and passenger) behavior, such as higher safety belt use rates. All of these will tend to reduce the absolute number of fatalities. The agency estimated the overall change in calculated fatalities by calendar year after adjusting for ESC, Side Impact Protection, and other Federal safety standards and behavioral changes projected through this time period. Thus, while the percentage increases in Kahane (2011) were applied, the reduced base has resulted in smaller absolute increases than those that were predicted in the 2003 report.

The agency examined the impacts of identifiable safety trends over the lifetime of the vehicles produced in each model year. An estimate of these impacts was contained in a previous agency report.[410] The impacts were estimated on a year-by-year basis, but could be examined in a combined fashion. The agency assumed that the safety trends will result in a reduction in the target population of fatalities from which the weight impacts are derived. Using this method, we found a 12.6 percent reduction in fatality levels between 2007 and 2020 for the combination of safety standards and behavioral changes anticipated (ESC, head-curtain air bags, and increase belt use). Since the same safety standards are taking effect in the same years, the estimates derived from applying Kahane's percentages to a baseline of 2007 fatalities were thus multiplied by 0.874 to account for changes that the agency believes will take place in passenger car and light truck safety between the 2007 baseline on-road fleet used for this particular safety analysis and year 2025.

After applying these percentage increases to the estimated weight reductions per vehicle size by model year assumed in the Volpe model, Table IX-4 shows the results of NHTSA's safety analysis separately for each model year[411]. These are estimated increases or decreases in fatalities over the lifetime of the model year fleet. A positive number means that fatalities are projected to increase, a negative number ( ) means that fatalities are projected to decrease. The results are significantly affected by the assumptions put into the Volpe model to take more weight out of the heavy LTVs than out of other vehicles. Since the negative coefficients only appear for LTVs greater than 3,870 lbs., an improvement in safety can only occur if more weight is taken out of heavy light trucks than passenger cars or smaller light trucks.

Combining passenger car and light truck estimates for the Preferred Alternative results in a decrease in fatalities over the lifetime of the nine model years of MY 2017-2025 of 13 fatalities, broken up into an increase of 84 fatalities in passenger cars and a decrease of 97 fatalities in light trucks. The effects on fatalities range from a combined decrease of 247 fatalities for the 6% alternative to a combined increase of 54 fatalities for the 3% alternative. The difference in the results by alternative depends upon how much weight reduction is used in that alternative and the types and sizes of vehicles that the weight reduction applies to.

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[410] Blincoe, L. and Shankar, U, "The Impact of Safety Standards and Behavioral Trends on Motor Vehicle Fatality Rates," DOT HS 810 777, January 2007. See Table 4 comparing 2020 to 2007 (37,906/43,363 = 12.6% reduction (1-.126 = .874). Since 2008 was a recession year, it does not seem appropriate to use that as a baseline. We believe this same ratio should hold for this analysis which should compare 2025 to 2008. Thus, we are inclined to continue to use the same ration.

[411] NHTSA has changed the definitions of a passenger car and light truck for fuel economy purposes between the time of the Kahane 2003 analysis and this final rule. About 1.4 million 2 wheel drive SUVs have been redefined as passenger cars instead of light trucks. The Kahane 2011 analysis continues with the definitions used in the Kahane 2003 analysis. Thus, there are different definitions between Tables IX-1 and IX-2 (which use the old definitions) and Table IX-3 (which uses the new definitions).

Additionally, the societal impacts of increasing fatalities can be monetized using NHTSA's estimated comprehensive cost per life of $6,316,821 in 2009 dollars. This consists of a value of a statistical life of $6.0 million plus external economic costs associated with fatalities such as medical care, insurance administration costs and legal costs.[412] Typically, NHTSA would also estimate the impact on injuries and add that to the societal costs of fatalities, but in this case NHTSA does not have a model estimating the impact of weight on injuries. However, based on past studies, fatalities account for roughly 44 percent of total comprehensive costs due to injury.[413] If weight impacts non-fatal injuries roughly proportional to its impact on fatalities, then total costs would be roughly 2.27 times the value of fatalities alone, or around $14.36 million per fatality. The potential societal costs for fatalities and injuries combined are also shown in Table IX-3.

Decreases in societal costs over the lifetime of the nine model years are $180 million for the Preferred Alternative with the range of estimates by alternative from a decrease of $3,546 million for the 6% alternative to an increase of $770 million for the 3% alternative.

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[412] Blincoe et al, The Economic Impact of Motor Vehicle Crashes 2000, May 2002. Data from this report were updated for inflation and combined with the current DOT guidance on value of a statistical life to estimate the comprehensive value of a statistical life. Available at http://www-nrd.nhtsa.dot.gov/Pubs/809446.PDF (last accessed November 14, 2011) or Docket No. NHTSA-2010-0131

[413] Based on data in Blincoe et al updated for inflation and reflecting the Department's current VSL of $6.0 million in 2009 dollars.

Table IX-3a
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
Preferred Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	2	4	15	14	15
Light Trucks	(6)	(16)	0	(18)	(14)
Total	(4)	(12)	16	(4)	1
Millions of Dollars					
Passenger Cars	$ 34	$ 51	$ 219	$ 201	$ 211
Light Trucks	$ (88)	$ (225)	$ 6	$ (259)	$ (203)
Total	$ (53)	$ (174)	$ 225	$ (58)	$ 8
Fatalities	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	11	13	5	6	84
Light Trucks	(20)	(16)	(9)	2	(97)
Total	(9)	(3)	(4)	8	(13)
Millions of Dollars					
Passenger Cars	$ 158	$ 184	$ 75	$ 79	$ 1,213
Light Trucks	$ (294)	$ (233)	$ (126)	$ 28	$(1,393)
Total	$ (135)	$ (48)	$ (51)	$ 108	$ (180)

Table IX-3b
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
1% Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	0	4	11	12	12
Light Trucks	(3)	(4)	(10)	(16)	(17)
Total	(3)	(0)	1	(4)	(5)
Millions of Dollars					
Passenger Cars	$ 1	$ 61	$ 155	$ 169	$ 177
Light Trucks	$ (43)	$ (64)	$ (142)	$ (231)	$ (251)
Total	$ (42)	$ (4)	$ 13	$ (62)	$ (74)
Fatalities	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	13	11	12	7	82
Light Trucks	(21)	(21)	(17)	(18)	(129)
Total	(8)	(10)	(6)	(11)	(46)
Millions of Dollars					
Passenger Cars	$ 182	$ 163	$ 170	$ 106	$ 1,184
Light Trucks	$ (298)	$ (305)	$ (249)	$ (264)	$(1,848)
Total	$ (116)	$ (142)	$ (79)	$ (158)	$ (665)

Table IX-3c
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
2% Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	2	7	17	19	20	18	15	14	10	123
Light Trucks	(1)	(5)	(2)	(9)	(12)	(20)	(26)	(6)	(9)	(89)
Total	1	3	15	10	9	(2)	(11)	8	1	34
Millions of Dollars										
Passenger Cars	$ 29	$ 105	$ 243	$ 273	$ 291	$ 265	$ 215	$ 199	$ 148	$ 1,770
Light Trucks	$ (18)	$ (66)	$ (25)	$ (130)	$ (168)	$ (289)	$ (369)	$ (89)	$ (130)	$(1,284)
Total	$ 11	$ 39	$ 218	$ 144	$ 123	$ (23)	$ (154)	$ 110	$ 19	$ 487

Table IX-3d
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
3% Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	2	5	14	17	17
Light Trucks	(3)	(17)	(1)	(20)	(8)
Total	(1)	(12)	12	(3)	9
Millions of Dollars					
Passenger Cars	$ 24	$ 67	$ 194	$ 246	$ 242
Light Trucks	$ (39)	$ (240)	$ (21)	$ (291)	$ (112)
Total	$ (15)	$ (173)	$ 173	$ (45)	$ 130
Fatalities	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	15	17	15	11	112
Light Trucks	(10)	(9)	(4)	13	(58)
Total	6	8	11	24	54
Millions of Dollars					
Passenger Cars	$ 222	$ 237	$ 222	$ 154	$ 1,608
Light Trucks	$ (143)	$ (123)	$ (57)	$ 188	$ (838)
Total	$ 80	$ 114	$ 165	$ 342	$ 770

Table IX-3e
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
4% Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	2	1	9	7	6
Light Trucks	(3)	(19)	(9)	(37)	(16)
Total	(1)	(18)	(0)	(30)	(10)
Millions of Dollars					
Passenger Cars	$ 27	$ 10	$ 132	$ 93	$ 86
Light Trucks	$ (47)	$ (266)	$ (136)	$ (526)	$ (225)
Total	$ (20)	$ (256)	$ (3)	$ (432)	$ (139)
Fatalities	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	3	7	6	7	47
Light Trucks	(16)	(13)	(12)	5	(120)
Total	(14)	(6)	(5)	12	(72)
Millions of Dollars					
Passenger Cars	$ 38	$ 106	$ 87	$ 100	$ 679
Light Trucks	$ (235)	$ (194)	$ (166)	$ 77	$(1,718)
Total	$ (197)	$ (88)	$ (79)	$ 177	$(1,039)

Table IX-3f
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
5% Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	2	5	16	12	12
Light Trucks	(4)	(22)	(10)	(47)	(48)
Total	(2)	(17)	6	(35)	(36)
Millions of Dollars					
Passenger Cars	$ 29	$ 75	$ 234	$ 174	$ 178
Light Trucks	$ (60)	$ (318)	$ (141)	$ (677)	$ (696)
Total	$ (31)	$ (242)	$ 93	$ (503)	$ (518)
Fatalities	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	8	11	(1)	(1)	65
Light Trucks	(53)	(43)	(44)	(21)	(293)
Total	(45)	(32)	(45)	(22)	(228)
Millions of Dollars					
Passenger Cars	$ 118	$ 152	$ (21)	$ (11)	$ 927
Light Trucks	$ (766)	$ (613)	$ (629)	$ (302)	$(4,200)
Total	$ (648)	$ (461)	$ (650)	$ (313)	$(3,273)

Table IX-3g
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
6% Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	1	5	15	11	11	7	8	(4)	(2)	53
Light Trucks	(5)	(18)	(11)	(49)	(45)	(52)	(48)	(49)	(22)	(300)
Total	(4)	(13)	4	(38)	(34)	(45)	(40)	(53)	(25)	(247)
Millions of Dollars										
Passenger Cars	$ 20	$ 69	$ 217	$ 164	$ 164	$ 105	$ 112	$ (57)	$ (32)	$ 762
Light Trucks	$ (72)	$ (261)	$ (159)	$ (704)	$ (646)	$ (753)	$ (687)	$ (704)	$ (322)	$(4,308)
Total	$ (52)	$ (192)	$ 58	$ (539)	$ (482)	$ (648)	$ (576)	$ (761)	$ (354)	$(3,546)

Table IX-3h
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
7% Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	1	(0)	10	6	6	3	8	(3)	(2)	27
Light Trucks	(5)	(21)	0	(43)	(23)	(34)	(21)	(32)	(6)	(184)
Total	(4)	(21)	10	(37)	(17)	(31)	(13)	(35)	(8)	(157)
Millions of Dollars										
Passenger Cars	$ 9	$ (5)	$ 138	$ 83	$ 79	$ 41	$ 117	$ (48)	$ (22)	$ 393
Light Trucks	$ (72)	$ (297)	$ 5	$ (616)	$ (324)	$ (493)	$ (301)	$ (453)	$ (91)	$(2,640)
Total	$ (63)	$ (301)	$ 144	$ (533)	$ (245)	$ (451)	$ (185)	$ (501)	$ (113)	$(2,248)

Table IX-3i
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
Maximum Net Benefit Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	2	11	21	26	25
Light Trucks	(8)	(19)	(9)	(37)	(25)
Total	(6)	(8)	12	(12)	0
Millions of Dollars					
Passenger Cars	$ 26	$ 151	$ 297	$ 367	$ 365
Light Trucks	$ (111)	$ (271)	$ (127)	$ (533)	$ (360)
Total	$ (84)	$ (119)	$ 169	$ (166)	$ 6
Fatalities	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	26	25	24	22	182
Light Trucks	(32)	(22)	(23)	(9)	(184)
Total	(6)	3	0	13	(2)
Millions of Dollars					
Passenger Cars	$ 376	$ 364	$ 339	$ 323	$ 2,608
Light Trucks	$ (455)	$ (316)	$ (334)	$ (131)	$(2,637)
Total	$ (80)	$ 48	$ 6	$ 192	$ (29)

Table IX-3j
Comparison of the Calculated Weight Safety-Related Fatality Impacts over the Lifetime of the Vehicles Produced in each Model Year
Total Cost = Total Benefit Alternative

Fatalities	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars	0	9	18	17	17
Light Trucks	(10)	(21)	(9)	(38)	(22)
Total	(10)	(12)	9	(22)	(6)
Millions of Dollars					
Passenger Cars	$ 1	$ 129	$ 253	$ 240	$ 241
Light Trucks	$ (145)	$ (298)	$ (127)	$ (552)	$ (323)
Total	$ (144)	$ (169)	$ 125	$ (311)	$ (82)
Fatalities	MY 2022	MY 2023	MY 2024	MY 2025	Total
Passenger Cars	17	11	5	6	99
Light Trucks	(29)	(19)	(20)	(5)	(173)
Total	(12)	(8)	(14)	1	(74)
Millions of Dollars					
Passenger Cars	$ 239	$ 153	$ 78	$ 81	$ 1,415
Light Trucks	$ (417)	$ (273)	$ (282)	$ (65)	$(2,481)
Total	$ (178)	$ (120)	$ (203)	$ 15	$(1,067)

X. NET BENEFITS AND SENSITIVITY ANALYSIS

This chapter compares the costs of technologies needed to make improvements in fuel economy with the potential benefits, expressed in total costs (millions of dollars) from a societal perspective for each model year. The costs do not include CAFE civil penalties estimated to be paid by manufacturers to NHTSA, since these are transfer payments. Thus, the total costs shown in this section do not match the total costs shown in Chapter VII. These are incremental costs and benefits compared to the adjusted baseline of MY 2016. A payback period is calculated, from the consumer's perspective. Finally, sensitivity analyses are also performed on some of the assumptions made in this analysis.

Table X-1 provides the total incremental costs (in millions of dollars) from a societal perspective at a 3 percent discount rate. Table X-2 presents the same set of total incremental costs at a 7 percent discount rate. Table X-3 provides the total benefits at a 3 percent discount rate from a societal perspective for all vehicles produced. Table X-4 presents total benefits at a 7 percent discount rate from a societal perspective for all vehicles produced.

Table X-5 shows the total net benefits (in millions of dollars) from a societal perspective at a 3 percent discount rate for the projected fleet of sales for MY 2017 – MY 2025. Table X-6 is analogous to Table X-5, with use of a 7 percent discount rate.

Total costs follow a predictable pattern with costs rising to reflect the more expensive technologies that manufacturers must apply in order to achieve the CAFE levels that are required under the more aggressive alternatives. With a 3 percent discount rate, total compliance costs for the passenger car fleet under the Total Cost = Total Benefit alternative are 1.5 times greater than those of the Preferred Alternative. In the case a 7 percent discount rate, this ratio increases slightly to 1.6. For the light truck fleet, in the case of a 3 percent discount rate, total compliance costs are 2.5 times higher under the Total Cost = Total Benefit alternative than under the Preferred Alternative; in the case of a 7 percent discount rate, this ratio increases to 2.9.

In Tables X-3 and X-4, lifetime societal benefits follow a similar predictable pattern, with higher benefits associated with the more expensive technologies that are enabled under the more aggressive alternatives. For the combined fleet, the TC=TB alternative produces gross benefits roughly 1.47 times those of the Preferred Alternative under a 3% discount rate and 1.45 times those of the Preferred Alternative under a 7% discount rate.

Tables X-5 and X-6 present the net benefits to society produced by each alternative. Each alternative, including the Preferred Alternative, results in a net benefit to society. In Table X-5, the combined net benefit for passenger cars and light trucks under all nine model years ranges from $247 billion under the 2% Annual Increase alternative to $424 billion under the 7% Annual Increase alternative. Net benefits for the Preferred Alternative (the total under both vehicle types and all model years) are $344 billion at the 3% discount rate.

Table X-1a
Incremental Total Cost – Societal Perspective
Passenger Cars, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$2,084	$4,438	$7,387	$10,687	$13,646
2% Annual Increase	$903	$2,175	$3,631	$5,074	$6,270
3% Annual Increase	$1,501	$3,656	$5,944	$8,496	$10,641
4% Annual Increase	$2,869	$5,658	$8,722	$12,378	$15,189
5% Annual Increase	$4,765	$8,300	$11,645	$15,996	$21,485
6% Annual Increase	$6,720	$11,114	$14,888	$20,745	$24,643
7% Annual Increase	$7,778	$12,706	$16,630	$22,949	$26,114
Max Net Benefits	$8,242	$9,939	$13,837	$15,679	$17,108
Total Cost = Total Benefit	$10,185	$12,707	$14,531	$16,900	$20,081
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$15,928	$20,201	$24,329	$28,590	$127,289
2% Annual Increase	$7,381	$8,270	$9,772	$10,932	$54,407
3% Annual Increase	$12,407	$14,188	$16,599	$19,728	$93,159
4% Annual Increase	$17,338	$20,728	$26,183	$29,272	$138,337
5% Annual Increase	$24,264	$28,598	$40,437	$42,329	$197,819
6% Annual Increase	$28,631	$35,382	$54,306	$55,339	$251,768
7% Annual Increase	$31,378	$43,568	$59,906	$61,921	$282,950
Max Net Benefits	$17,716	$18,916	$20,233	$20,848	$142,517
Total Cost = Total Benefit	$24,940	$31,743	$37,364	$37,809	$206,259

Table X-1b
Incremental Total Cost – Societal Perspective
Light Trucks, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks										
Preferred Alternative	$487	$1,473	$2,998	$4,284	$6,200	$7,070	$7,909	$9,150	$10,720	$50,290
2% Annual Increase	$965	$1,707	$2,741	$3,385	$4,148	$4,510	$4,962	$5,466	$5,727	$33,612
3% Annual Increase	$1,527	$2,666	$3,950	$5,380	$6,897	$7,791	$8,407	$9,363	$10,512	$56,494
4% Annual Increase	$2,464	$4,022	$6,265	$8,680	$11,053	$12,318	$14,014	$15,053	$16,852	$90,720
5% Annual Increase	$3,510	$5,650	$8,366	$11,507	$14,798	$16,419	$18,008	$22,139	$23,318	$123,714
6% Annual Increase	$5,270	$7,906	$11,081	$14,955	$17,276	$19,048	$21,252	$24,302	$25,513	$146,602
7% Annual Increase	$6,298	$8,888	$11,960	$15,852	$17,533	$20,706	$23,318	$27,363	$26,529	$158,447
Max Net Benefits	$8,777	$9,847	$11,314	$13,683	$15,633	$16,360	$18,460	$21,140	$23,012	$138,225
Total Cost = Total Benefit	$8,738	$9,875	$11,324	$13,643	$15,766	$16,450	$19,110	$21,831	$23,616	$140,353

Table X-1c
Incremental Total Cost – Societal Perspective
Combined, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$2,571	$5,910	$10,386	$14,971	$19,845	$22,998	$28,110	$33,479	$39,310	$177,579
2% Annual Increase	$1,868	$3,883	$6,372	$8,459	$10,418	$11,891	$13,233	$15,238	$16,659	$88,020
3% Annual Increase	$3,028	$6,322	$9,894	$13,875	$17,538	$20,199	$22,595	$25,962	$30,240	$149,653
4% Annual Increase	$5,332	$9,680	$14,987	$21,058	$26,242	$29,657	$34,743	$41,235	$46,123	$229,057
5% Annual Increase	$8,275	$13,949	$20,012	$27,502	$36,284	$40,683	$46,606	$62,576	$65,647	$321,534
6% Annual Increase	$11,990	$19,020	$25,969	$35,699	$41,919	$47,679	$56,634	$78,608	$80,852	$398,370
7% Annual Increase	$14,076	$21,594	$28,590	$38,801	$43,647	$52,084	$66,887	$87,269	$88,450	$441,397
Max Net Benefits	$17,019	$19,786	$25,151	$29,362	$32,741	$34,076	$37,376	$41,373	$43,860	$280,743
Total Cost = Total Benefit	$18,923	$22,582	$25,855	$30,544	$35,847	$41,390	$50,853	$59,195	$61,425	$346,613

Table X-2a
Incremental Total Cost – Societal Perspective
Passenger Cars, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$1,952	$4,190	$6,990	$10,151	$12,998
2% Annual Increase	$832	$2,033	$3,400	$4,760	$5,884
3% Annual Increase	$1,390	$3,431	$5,593	$8,024	$10,072
4% Annual Increase	$2,704	$5,365	$8,281	$11,786	$14,489
5% Annual Increase	$4,537	$7,932	$11,118	$15,300	$20,627
6% Annual Increase	$6,438	$10,673	$14,283	$19,946	$23,726
7% Annual Increase	$7,456	$12,220	$15,980	$22,103	$25,166
Max Net Benefits	$7,808	$9,439	$13,194	$14,978	$16,298
Total Cost = Total Benefit	$9,777	$12,214	$13,975	$16,168	$19,157
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$15,182	$19,320	$23,300	$27,379	$121,462
2% Annual Increase	$6,932	$7,769	$9,191	$10,283	$51,083
3% Annual Increase	$11,754	$13,454	$15,756	$18,751	$88,226
4% Annual Increase	$16,546	$19,831	$25,123	$28,054	$132,178
5% Annual Increase	$23,316	$27,525	$39,107	$40,819	$190,281
6% Annual Increase	$27,612	$34,198	$52,730	$53,485	$243,091
7% Annual Increase	$30,293	$42,227	$58,185	$59,894	$273,523
Max Net Benefits	$16,873	$17,824	$19,262	$19,898	$135,574
Total Cost = Total Benefit	$21,552	$28,551	$34,276	$35,020	$190,689

Table X-2b
Incremental Total Cost – Societal Perspective
Light Trucks, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$453	$1,373	$2,785	$3,996	$5,794
2% Annual Increase	$900	$1,589	$2,535	$3,135	$3,835
3% Annual Increase	$1,432	$2,492	$3,674	$5,028	$6,460
4% Annual Increase	$2,327	$3,797	$5,918	$8,240	$10,510
5% Annual Increase	$3,339	$5,381	$7,971	$11,005	$14,174
6% Annual Increase	$5,053	$7,582	$10,615	$14,373	$16,601
7% Annual Increase	$6,062	$8,542	$11,472	$15,248	$16,853
Max Net Benefits	$6,996	$7,931	$9,457	$10,754	$12,590
Total Cost = Total Benefit	$8,476	$9,542	$10,900	$13,125	$15,077
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$6,615	$7,411	$8,587	$10,086	$47,101
2% Annual Increase	$4,170	$4,591	$5,063	$5,301	$31,119
3% Annual Increase	$7,305	$7,889	$8,797	$9,892	$52,970
4% Annual Increase	$11,716	$13,357	$14,352	$16,076	$86,292
5% Annual Increase	$15,733	$17,269	$21,314	$22,414	$118,599
6% Annual Increase	$18,310	$20,457	$23,437	$24,572	$140,998
7% Annual Increase	$19,956	$22,500	$26,455	$25,565	$152,653
Max Net Benefits	$12,973	$13,703	$14,377	$14,024	$102,806
Total Cost = Total Benefit	$15,727	$18,372	$21,063	$22,752	$135,035

Table X-2c
Incremental Total Cost – Societal Perspective
Combined, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$2,405	$5,564	$9,775	$14,147	$18,792	$21,797	$26,731	$31,886	$37,465	$168,563
2% Annual Increase	$1,731	$3,622	$5,935	$7,895	$9,719	$11,101	$12,360	$14,253	$15,584	$82,201
3% Annual Increase	$2,822	$5,923	$9,267	$13,053	$16,533	$19,060	$21,343	$24,552	$28,643	$141,196
4% Annual Increase	$5,031	$9,162	$14,199	$20,026	$24,999	$28,262	$33,188	$39,474	$44,130	$218,471
5% Annual Increase	$7,876	$13,313	$19,089	$26,305	$34,801	$39,049	$44,795	$60,420	$63,233	$308,881
6% Annual Increase	$11,491	$18,255	$24,898	$34,319	$40,327	$45,921	$54,654	$76,166	$78,057	$384,088
7% Annual Increase	$13,518	$20,762	$27,452	$37,351	$42,019	$50,249	$64,726	$84,640	$85,458	$426,176
Max Net Benefits	$14,804	$17,369	$22,651	$25,732	$28,888	$29,846	$31,527	$33,639	$33,923	$238,380
Total Cost = Total Benefit	$18,253	$21,756	$24,875	$29,294	$34,234	$37,279	$46,922	$55,340	$57,772	$325,725

Table X-3a
Present Value of Lifetime Societal Benefits by Alternative
Passenger Cars, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars										
Preferred Alternative	$6,750	$12,833	$20,672	$28,358	$34,294	$39,805	$47,859	$56,388	$66,112	$313,071
2% Annual Increase	$3,622	$7,262	$11,776	$16,236	$20,143	$23,604	$26,497	$30,911	$34,501	$174,553
3% Annual Increase	$5,598	$11,552	$18,161	$24,751	$30,143	$34,857	$39,406	$45,496	$52,720	$262,683
4% Annual Increase	$8,455	$15,431	$23,139	$31,481	$37,386	$42,556	$48,624	$57,757	$66,009	$330,837
5% Annual Increase	$11,534	$19,215	$27,671	$36,976	$44,980	$50,012	$57,048	$71,273	$80,929	$399,638
6% Annual Increase	$14,548	$22,794	$31,282	$41,881	$48,717	$54,124	$62,710	$80,526	$92,493	$449,074
7% Annual Increase	$16,797	$25,535	$34,187	$44,924	$50,687	$58,268	$70,271	$85,920	$98,104	$484,693
Max Net Benefits	$18,546	$21,999	$28,842	$33,951	$38,758	$41,099	$44,553	$48,402	$52,662	$328,812
Total Cost = Total Benefit	$21,088	$25,817	$31,085	$36,734	$44,172	$50,911	$60,049	$68,539	$76,016	$414,411

Table X-3b
Present Value of Lifetime Societal Benefits by Alternative
Light Trucks, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks										
Preferred Alternative	$2,137	$6,369	$13,480	$18,546	$26,283	$29,699	$32,701	$37,346	$42,187	$208,747
2% Annual Increase	$4,051	$7,459	$12,945	$15,888	$20,031	$21,938	$24,108	$26,288	$27,986	$160,694
3% Annual Increase	$6,022	$11,100	$17,537	$22,627	$28,308	$31,730	$34,024	$37,551	$41,185	$230,084
4% Annual Increase	$8,732	$14,377	$22,226	$28,652	$35,476	$39,695	$43,420	$46,721	$52,086	$291,385
5% Annual Increase	$10,894	$17,210	$25,370	$32,751	$41,140	$45,536	$49,305	$55,738	$61,358	$339,302
6% Annual Increase	$13,815	$19,716	$28,961	$37,255	$43,344	$47,477	$51,776	$57,416	$63,617	$363,378
7% Annual Increase	$15,023	$21,118	$30,523	$38,472	$43,510	$49,951	$54,628	$61,530	$65,588	$380,343
Max Net Benefits	$19,388	$22,289	$28,681	$34,513	$41,336	$44,002	$48,274	$53,343	$59,539	$351,366
Total Cost = Total Benefit	$19,456	$22,218	$28,575	$34,503	$41,455	$44,073	$49,063	$54,118	$60,760	$354,221

Table X-3c
Present Value of Lifetime Societal Benefits by Alternative
Combined, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$8,887	$19,202	$34,152	$46,905	$60,577	$69,504	$80,560	$93,734	$108,299	$521,818
2% Annual Increase	$7,674	$14,721	$24,721	$32,124	$40,175	$45,542	$50,604	$57,199	$62,487	$335,246
3% Annual Increase	$11,621	$22,652	$35,698	$47,378	$58,450	$66,587	$73,430	$83,047	$93,905	$492,767
4% Annual Increase	$17,188	$29,808	$45,365	$60,132	$72,862	$82,251	$92,044	$104,478	$118,095	$622,223
5% Annual Increase	$22,429	$36,424	$53,041	$69,727	$86,120	$95,548	$106,353	$127,011	$142,287	$738,940
6% Annual Increase	$28,363	$42,511	$60,243	$79,135	$92,061	$101,601	$114,486	$137,942	$156,109	$812,452
7% Annual Increase	$31,821	$46,653	$64,710	$83,396	$94,197	$108,219	$124,898	$147,451	$163,692	$865,036
Max Net Benefits	$37,934	$44,288	$57,523	$68,464	$80,094	$85,101	$92,827	$101,746	$112,202	$680,178
Total Cost = Total Benefit	$40,543	$48,035	$59,661	$71,237	$85,627	$94,984	$109,112	$122,656	$136,776	$768,632

Table X-4a
Present Value of Lifetime Societal Benefits by Alternative
Passenger Cars, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$5,504	$10,466	$16,889	$23,167	$28,042
2% Annual Increase	$2,953	$5,923	$9,622	$13,265	$16,475
3% Annual Increase	$4,570	$9,429	$14,843	$20,227	$24,656
4% Annual Increase	$6,894	$12,580	$18,901	$25,714	$30,562
5% Annual Increase	$9,402	$15,660	$22,593	$30,195	$36,764
6% Annual Increase	$11,860	$18,576	$25,531	$34,194	$39,820
7% Annual Increase	$13,694	$20,822	$27,918	$36,693	$41,439
Max Net Benefits	$14,994	$17,744	$23,379	$27,656	$31,492
Total Cost = Total Benefit	$17,186	$21,046	$25,303	$29,954	$36,030
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$32,579	$39,157	$46,184	$54,199	$256,188
2% Annual Increase	$19,329	$21,712	$25,357	$28,327	$142,964
3% Annual Increase	$28,538	$32,287	$37,316	$43,271	$215,136
4% Annual Increase	$34,828	$39,799	$47,324	$54,135	$270,737
5% Annual Increase	$40,916	$46,723	$58,396	$66,356	$327,006
6% Annual Increase	$44,287	$51,320	$65,945	$75,812	$367,345
7% Annual Increase	$47,683	$57,520	$70,373	$80,417	$396,559
Max Net Benefits	$33,410	$35,960	$39,361	$42,961	$266,956
Total Cost = Total Benefit	$39,729	$47,479	$54,739	$60,797	$332,264

Table X-4b
Present Value of Lifetime Societal Benefits by Alternative
Light Trucks, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$1,714	$5,110	$10,792	$14,881	$21,096
2% Annual Increase	$3,238	$5,971	$10,366	$12,741	$16,080
3% Annual Increase	$4,815	$8,896	$14,042	$18,150	$22,711
4% Annual Increase	$6,980	$11,515	$17,798	$22,990	$28,464
5% Annual Increase	$8,709	$13,782	$20,310	$26,277	$33,041
6% Annual Increase	$11,042	$15,767	$23,168	$29,874	$34,786
7% Annual Increase	$12,007	$16,890	$24,408	$30,838	$34,884
Max Net Benefits	$13,347	$15,816	$21,135	$24,755	$30,508
Total Cost = Total Benefit	$15,633	$17,816	$22,922	$27,708	$33,146
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$23,867	$26,298	$30,053	$33,963	$167,774
2% Annual Increase	$17,637	$19,402	$21,156	$22,545	$129,137
3% Annual Increase	$25,485	$27,351	$30,211	$33,151	$184,812
4% Annual Increase	$31,881	$34,892	$37,579	$41,915	$234,013
5% Annual Increase	$36,607	$39,649	$44,843	$49,381	$272,599
6% Annual Increase	$38,138	$41,611	$46,181	$51,179	$291,746
7% Annual Increase	$40,090	$43,864	$49,458	$52,742	$305,181
Max Net Benefits	$32,429	$34,672	$36,381	$37,726	$246,768
Total Cost = Total Benefit	$35,291	$39,397	$43,572	$48,941	$284,425

Table X-4c
Present Value of Lifetime Societal Benefits by Alternative
Combined, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$7,218	$15,576	$27,682	$38,047	$49,138	$56,447	$65,454	$76,237	$88,162	$423,961
2% Annual Increase	$6,192	$11,895	$19,988	$26,006	$32,555	$36,965	$41,114	$46,513	$50,872	$272,101
3% Annual Increase	$9,384	$18,325	$28,885	$38,377	$47,367	$54,023	$59,638	$67,527	$76,422	$399,948
4% Annual Increase	$13,874	$24,095	$36,699	$48,703	$59,027	$66,709	$74,691	$84,903	$96,049	$504,750
5% Annual Increase	$18,110	$29,442	$42,904	$56,471	$69,806	$77,523	$86,372	$103,239	$115,738	$599,605
6% Annual Increase	$22,902	$34,344	$48,698	$64,067	$74,606	$82,425	$92,932	$112,126	$126,991	$659,091
7% Annual Increase	$25,701	$37,712	$52,326	$67,531	$76,323	$87,773	$101,383	$119,831	$133,160	$701,740
Max Net Benefits	$28,342	$33,559	$44,513	$52,411	$62,000	$65,839	$70,631	$75,742	$80,686	$513,724
Total Cost = Total Benefit	$32,820	$38,861	$48,224	$57,662	$69,176	$75,020	$86,877	$98,311	$109,738	$616,689

Table X-5a
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
Passenger Cars, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Passenger Cars					
Preferred Alternative	$4,666	$8,396	$13,285	$17,671	$20,648
2% Annual Increase	$2,719	$5,087	$8,145	$11,163	$13,874
3% Annual Increase	$4,097	$7,896	$12,217	$16,255	$19,502
4% Annual Increase	$5,587	$9,772	$14,417	$19,103	$22,197
5% Annual Increase	$6,770	$10,915	$16,026	$20,981	$23,494
6% Annual Increase	$7,828	$11,680	$16,394	$21,136	$24,074
7% Annual Increase	$9,019	$12,829	$17,557	$21,975	$24,573
Max Net Benefits	$10,304	$12,060	$15,005	$18,272	$21,650
Total Cost = Total Benefit	$10,902	$13,110	$16,554	$19,833	$24,091
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars					
Preferred Alternative	$23,877	$27,658	$32,059	$37,522	$185,782
2% Annual Increase	$16,223	$18,226	$21,139	$23,570	$120,145
3% Annual Increase	$22,450	$25,217	$28,897	$32,992	$169,524
4% Annual Increase	$25,218	$27,896	$31,575	$36,737	$192,501
5% Annual Increase	$25,748	$28,449	$30,836	$38,600	$201,819
6% Annual Increase	$25,493	$27,328	$26,220	$37,154	$197,306
7% Annual Increase	$26,890	$26,702	$26,014	$36,183	$201,743
Max Net Benefits	$23,383	$25,636	$28,169	$31,815	$186,295
Total Cost = Total Benefit	$25,971	$28,307	$31,175	$38,207	$208,151

Table X-5b
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
Light Trucks, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$1,650	$4,896	$10,482	$14,262	$20,084
2% Annual Increase	$3,087	$5,752	$10,204	$12,503	$15,883
3% Annual Increase	$4,495	$8,434	$13,587	$17,247	$21,411
4% Annual Increase	$6,269	$10,355	$15,961	$19,972	$24,424
5% Annual Increase	$7,384	$11,560	$17,004	$21,244	$26,342
6% Annual Increase	$8,545	$11,810	$17,880	$22,300	$26,068
7% Annual Increase	$8,725	$12,230	$18,563	$22,620	$25,977
Max Net Benefits	$10,611	$12,442	$17,367	$20,830	$25,703
Total Cost = Total Benefit	$10,718	$12,343	$17,252	$20,860	$25,688
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$22,629	$24,791	$28,196	$31,467	$158,457
2% Annual Increase	$17,428	$19,145	$20,822	$22,258	$127,082
3% Annual Increase	$23,939	$25,617	$28,188	$30,672	$173,590
4% Annual Increase	$27,376	$29,406	$31,668	$35,235	$200,665
5% Annual Increase	$29,117	$31,297	$33,599	$38,041	$215,587
6% Annual Increase	$28,430	$30,524	$33,114	$38,103	$216,776
7% Annual Increase	$29,245	$31,309	$34,167	$39,060	$221,896
Max Net Benefits	$27,642	$29,815	$32,204	$36,527	$213,141
Total Cost = Total Benefit	$27,623	$29,953	$32,286	$37,144	$213,868

Table X-5c
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
Combined, 3% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$6,316	$13,291	$23,766	$31,934	$40,732	$46,506	$52,450	$60,255	$68,989	$344,239
2% Annual Increase	$5,806	$10,838	$18,349	$23,666	$29,757	$33,651	$37,371	$41,961	$45,828	$247,227
3% Annual Increase	$8,592	$16,330	$25,803	$33,503	$40,913	$46,388	$50,835	$57,085	$63,665	$343,114
4% Annual Increase	$11,855	$20,128	$30,378	$39,075	$46,620	$52,594	$57,301	$63,243	$71,972	$393,166
5% Annual Increase	$14,154	$22,475	$33,030	$42,225	$49,836	$54,865	$59,746	$64,435	$76,640	$417,406
6% Annual Increase	$16,373	$23,491	$34,274	$43,436	$50,142	$53,922	$57,852	$59,334	$75,257	$414,082
7% Annual Increase	$17,744	$25,059	$36,120	$44,595	$50,550	$56,135	$58,012	$60,181	$75,242	$423,639
Max Net Benefits	$20,915	$24,502	$32,372	$39,103	$47,353	$51,025	$55,451	$60,373	$68,342	$399,436
Total Cost = Total Benefit	$21,620	$25,453	$33,806	$40,694	$49,780	$53,594	$58,259	$63,462	$75,351	$422,019

Table X-6a
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
Passenger Cars, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars										
Preferred Alternative	$3,552	$6,276	$9,900	$13,015	$15,044	$17,397	$19,837	$22,884	$26,820	$134,726
2% Annual Increase	$2,122	$3,891	$6,222	$8,505	$10,591	$12,397	$13,943	$16,167	$18,044	$91,881
3% Annual Increase	$3,179	$5,999	$9,250	$12,202	$14,584	$16,784	$18,833	$21,560	$24,520	$126,910
4% Annual Increase	$4,190	$7,216	$10,621	$13,927	$16,073	$18,282	$19,968	$22,202	$26,080	$138,558
5% Annual Increase	$4,865	$7,728	$11,475	$14,895	$16,137	$17,601	$19,197	$19,290	$25,537	$136,725
6% Annual Increase	$5,422	$7,903	$11,247	$14,248	$16,094	$16,675	$17,122	$13,215	$22,327	$124,255
7% Annual Increase	$6,238	$8,602	$11,937	$14,590	$16,274	$17,389	$15,293	$12,189	$20,524	$123,037
Max Net Benefits	$7,187	$8,305	$10,184	$12,678	$15,194	$16,537	$18,136	$20,099	$23,062	$131,382
Total Cost = Total Benefit	$7,410	$8,832	$11,328	$13,786	$16,873	$18,177	$18,928	$20,463	$25,777	$141,574

Table X-6b
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
Light Trucks, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021
Light Trucks					
Preferred Alternative	$1,261	$3,737	$8,007	$10,885	$15,302
2% Annual Increase	$2,339	$4,382	$7,831	$9,606	$12,245
3% Annual Increase	$3,383	$6,403	$10,368	$13,122	$16,251
4% Annual Increase	$4,654	$7,718	$11,880	$14,750	$17,954
5% Annual Increase	$5,370	$8,401	$12,340	$15,272	$18,868
6% Annual Increase	$5,990	$8,185	$12,553	$15,501	$18,185
7% Annual Increase	$5,945	$8,348	$12,936	$15,590	$18,031
Max Net Benefits	$6,351	$7,885	$11,678	$14,001	$17,918
Total Cost = Total Benefit	$7,157	$8,273	$12,022	$14,582	$18,069
Alternative	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Light Trucks					
Preferred Alternative	$17,252	$18,886	$21,466	$23,877	$120,673
2% Annual Increase	$13,467	$14,811	$16,093	$17,244	$98,019
3% Annual Increase	$18,180	$19,462	$21,415	$23,259	$131,842
4% Annual Increase	$20,165	$21,535	$23,227	$25,839	$147,721
5% Annual Increase	$20,874	$22,380	$23,529	$26,967	$154,000
6% Annual Increase	$19,828	$21,155	$22,745	$26,607	$150,748
7% Annual Increase	$20,134	$21,364	$23,003	$27,178	$152,528
Max Net Benefits	$19,456	$20,969	$22,003	$23,701	$143,962
Total Cost = Total Benefit	$19,563	$21,026	$22,509	$26,189	$149,390

Table X-6c
Net Total Benefits
Over the Vehicle's Lifetime – Present Value
Combined, 7% Discount Rate
(Millions of 2009 Dollars)

Alternative	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025	9-Year Total
Passenger Cars & Light Trucks										
Preferred Alternative	$4,813	$10,013	$17,907	$23,900	$30,346	$34,649	$38,724	$44,351	$50,697	$255,399
2% Annual Increase	$4,460	$8,273	$14,053	$18,111	$22,836	$25,864	$28,754	$32,260	$35,288	$189,900
3% Annual Increase	$6,562	$12,402	$19,617	$25,324	$30,835	$34,964	$38,295	$42,975	$47,778	$258,751
4% Annual Increase	$8,843	$14,934	$22,501	$28,677	$34,027	$38,447	$41,503	$45,429	$51,919	$286,279
5% Annual Increase	$10,234	$16,129	$23,815	$30,166	$35,005	$38,474	$41,578	$42,819	$52,504	$290,725
6% Annual Increase	$11,412	$16,088	$23,800	$29,749	$34,279	$36,503	$38,277	$35,960	$48,934	$275,003
7% Annual Increase	$12,183	$16,950	$24,873	$30,180	$34,305	$37,524	$36,657	$35,191	$47,702	$275,565
Max Net Benefits	$13,538	$16,190	$21,862	$26,678	$33,112	$35,993	$39,104	$42,102	$46,763	$275,344
Total Cost = Total Benefit	$14,567	$17,105	$23,349	$28,368	$34,942	$37,740	$39,954	$42,972	$51,966	$290,964

Breakdown of costs and benefits for the preferred alternative

Table X-7 provides a breakdown of the costs and benefits for the preferred alternative using a 3 percent and 7 percent discount rate, respectively.

Table X-7
Preferred Alternative
Cost and Benefit Estimates
Passenger Cars and Light Trucks Combined
MY 2017-2025 Combined
(Millions of 2009 Dollars)

	Undiscounted	Discounted, 3%	Discounted, 7%
Technology Costs	($132,137)	($132,137)	($132,137)
Social Costs and Benefits			
Lifetime Fuel Expenditures (Pretax)	$514,100	$416,456	$330,460
Consumer Surplus from Additional Driving	$11,185	$9,105	$7,242
Refueling Time Value	$18,755	$15,292	$12,217
Petroleum Market Externalities	$26,430	$21,547	$17,211
Congestion Costs	($36,711)	($30,040)	($24,015)
Accident Costs	($17,447)	($14,250)	($11,376)
Noise Costs	($695)	($568)	($454)
Fatality Costs	$79	$10	$10
CO2	$57,081	$45,614	$45,614
CO	$0	$0	$0
VOC	$731	$601	$483
NOX	$679	$594	$513
PM	$8,151	$6,705	$5,405
SOX	$6,627	$5,401	$4,313
Net Social Benefits	$588,966	$476,467	$387,623
Net Total Benefits	$456,830	$344,330	$255,486

Payback Period

The "payback period" represents the length of time required for a vehicle buyer to recoup, through savings in fuel use, the higher cost of purchasing a more fuel-efficient vehicle. Thus, only these two factors are considered (purchase price and fuel savings). When a higher CAFE standard requires a manufacturer to improve the fuel economy of some of its vehicle models, the manufacturer's added costs for doing so are generally reflected in higher prices for these models. While buyers of these models pay higher prices to purchase these vehicles, their improved fuel economy lowers the consumer's costs for purchasing fuel to operate them. Over time, buyers may recoup the higher purchase prices they pay for these vehicles in the form of savings in outlays for fuel. The length of time required to repay the higher cost of buying a more fuel-efficient vehicle is referred to as the buyer's payback period.

The length of this payback period depends on the initial increase in a vehicle's purchase price, the improvement in its fuel economy, the number of miles it is driven each year, and the retail price of fuel. We calculated payback periods using the fuel economy improvement and average price increase estimated to result from the standard, the future retail gasoline prices, and estimates of the number of miles vehicles are driven each year as they age. These calculations are taken from a consumer's perspective, not a societal perspective. Thus, only gasoline savings are included on the benefits side of the equation. The price of gasoline includes fuel taxes, since consumers generally only consider and respond to what they pay at the pump, and future savings are discounted to present value using a 3% discount rate or a 7% discount rate. The payback periods are estimated as an average for all manufacturers for the different alternatives. The payback periods for MY 2025 are shown in Table X-8. Discounted at 7%, the payback periods are slightly longer, since the benefits are discounted more.

Table X-8
Payback Period for MY 2025 Average Vehicles
(in years)
3% discount rate

	Passenger Cars	Light Trucks
Preferred	4.0	2.0
1%	2.2	1.1
2%	2.5	1.4
3%	3.3	2.0
4%	4.7	2.5
5%	5.1	3.6
6%	6.0	4.1
7%	6.6	4.4
Max Net	3.5	3.3
TC = TB	4.8	3.6

7% discount rate

	Passenger Cars	Light Trucks
Preferred	4.4	2.1
1%	2.3	1.2
2%	2.7	1.5
3%	3.5	2.1
4%	5.2	2.7
5%	5.7	3.9
6%	6.9	4.5
7%	7.7	4.9
Max Net	3.8	2.8
TC = TB	5.2	3.9

Sensitivity Analyses

The agency has performed several sensitivity analyses to examine important assumptions. All sensitivity analyses were based on the standard setting output of the Volpe model. We examine sensitivity with respect to the following economic parameters:

1) The price of gasoline: The main analysis (*i.e.*, the Reference Case) uses the AEO 2011 Reference Case estimate for the price of gasoline (see Table VIII-4). In this sensitivity analysis we examine the effect of using the AEO 2011 High Price Case or Low Price Case forecast estimates instead.

2) The rebound effect: The main analysis uses a rebound effect of 10 percent to project increased miles traveled as the cost per mile driven decreases. In the sensitivity analysis, we examine the effect of using a 5, 15, or 20 percent rebound effect instead.

3) The value of CO_2 benefits: The main analysis uses $22 per ton discounted at a 3 percent discount rate to quantify the benefits of reducing CO_2 emissions and $0.174 per gallon to quantify the benefits of reducing fuel consumption. In the sensitivity analysis, we examine the following values and discount rates applied only to the social cost of carbon to value carbon benefits, considering low, high, and very high valuations of approximately $5, $36, and $67 per ton, respectively with regard to the benefits of reducing CO_2 emissions.[414] These are the 2010 values, which increase over time. These values can be translated into cents per gallon by multiplying by 0.0089,[415] giving the following values:

   ($4.86 per ton CO_2) x 0.0089 = $0.043 per gallon discounted at 5%
   ($22.00 per ton CO_2) x 0.0089 = $0.196 per gallon discounted at 3% (used in the main analysis)
   ($36.13 per ton CO_2) x 0.0089 = $0.322 per gallon discounted at 2.5%
   And a 95th percentile estimate of
   ($66.88 per ton CO_2) x 0.0089 = $0.595 per gallon discounted at 3%

4) Military security: The main analysis does not assign a value to the military security benefits of reducing fuel consumption. In the sensitivity analysis, we examine the impact of using a value of 12 cents per gallon instead.

5) Consumer Benefit: The main analysis assumes there is no loss in value to consumers resulting from vehicles that have an increase in price and higher fuel economy. This sensitivity analysis assumes that there is a 25, or 50 percent loss in value to consumers –

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[414] The low, high, and very high valuations of $5, $36, and $67 are rounded for brevity; the exact values are $4.86, $36.13, and $66.88, respectively. While the model uses the unrounded values, the use of unrounded values is not intended to imply that the chosen values are precisely accurate to the nearest cent; rather, they are average levels resulting from the many published studies on the topic.

[415] The molecular weight of Carbon (C) is 12, the molecular weight of Oxygen (O) is 16, thus the molecular weight of CO_2 is 44. 1 gallon of gas weighs 2,819 grams, of that 2,433 grams are carbon. One ton of CO_2/One ton of C (44/12)* 2433grams C/gallon *1 ton/1000kg * 1 kg/1000g = (44 * 2433*1*1) / (12*1*1000 * 1000) = 0.0089. Thus, one ton of CO_2*0.0089 = 1 gallon of gasoline.

equivalent to the assumption that consumers will only value the calculated benefits they will achieve at 75, or 50 percent, respectively, of the main analysis estimates.

6) Battery cost: The agency conducted a sensitivity analysis of battery costs for HEV, PHEV and EV technologies. The ranges for battery costs are based on the recommendations from the technical experts in the field of battery energy storage technologies at Department of Energy (DOE) and Argonne National Laboratory (ANL). These ranges of battery costs are developed using the Battery Performance and Cost (BatPac) model developed by ANL funded by DOE[416]. The values for these ranges are shown in Table X-9 and are calculated with 95% confidence interval after analyzing the confidence bound using the BatPac model.

Table X-9
Suggested Confidence Bounds as Percentages 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%

In the NPRM central analysis, EPA developed direct manufacturing costs (DMC) for battery systems using ANL's BatPac model. For this sensitivity analysis, NHTSA scaled these central battery system costs by the percentages shown in Table X-9, per guidance from DOE and ANL experts on reasonable ranges for these costs. Figures X-1 to X-5 shows these battery system DMCs in terms of $/kW for HEV and $/kWh for 20-mile range PHEV (PHEV20), 40-mile range PHEV (PHEV40), 75-mile range EV (EV75), 100-mile range EV (EV100) and 150-mile range EV (EV150). We note that battery system cost varies with vehicle subclasses and driving range. Smaller batteries tend to be relatively more expensive per kWh because the cost for the battery management system, disconnect units and baseline thermal management system is the same from vehicle to vehicle for each type of electrification system, such as HEV, PHEV and EV (but varies between different electrification systems) and this cost is spread over fewer kWh for smaller vehicle. For example, the battery system cost for EVs ranges from $238/kWh for subcompact cars for EV75, to $167/kWh for minivan and large truck for EV150 in MY 2021.

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[416] Section 3.4.3.9 in TSD Chapter 3 has detailed descriptions of the history of the BatPac model and how the agencies used the BatPac model in this analysis.

Figure X-1
Battery System Direct Manufacture Cost (DMC) for P2 HEV

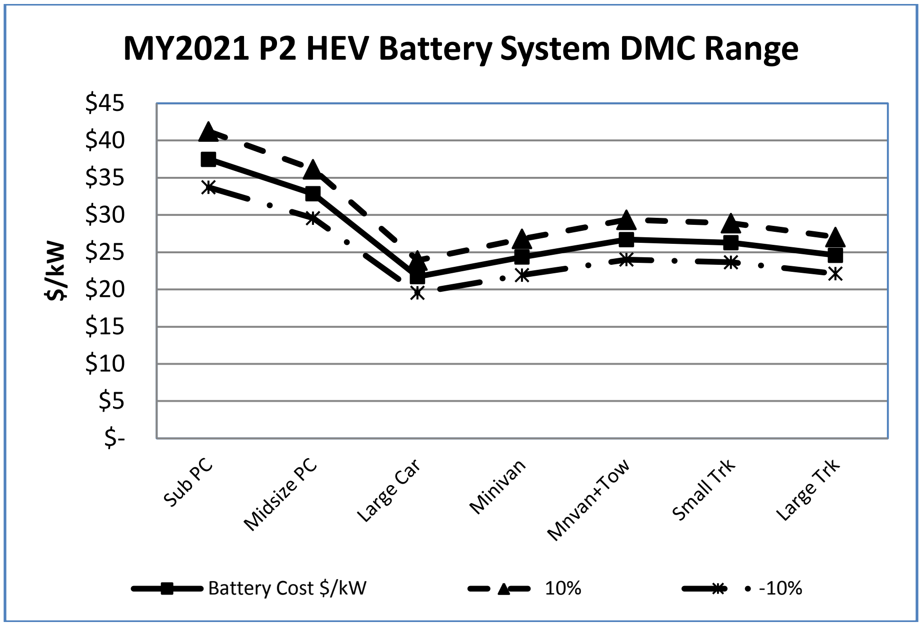


Figure X-2
Battery System Direct Manufacture Cost (DMC) for PHEV20

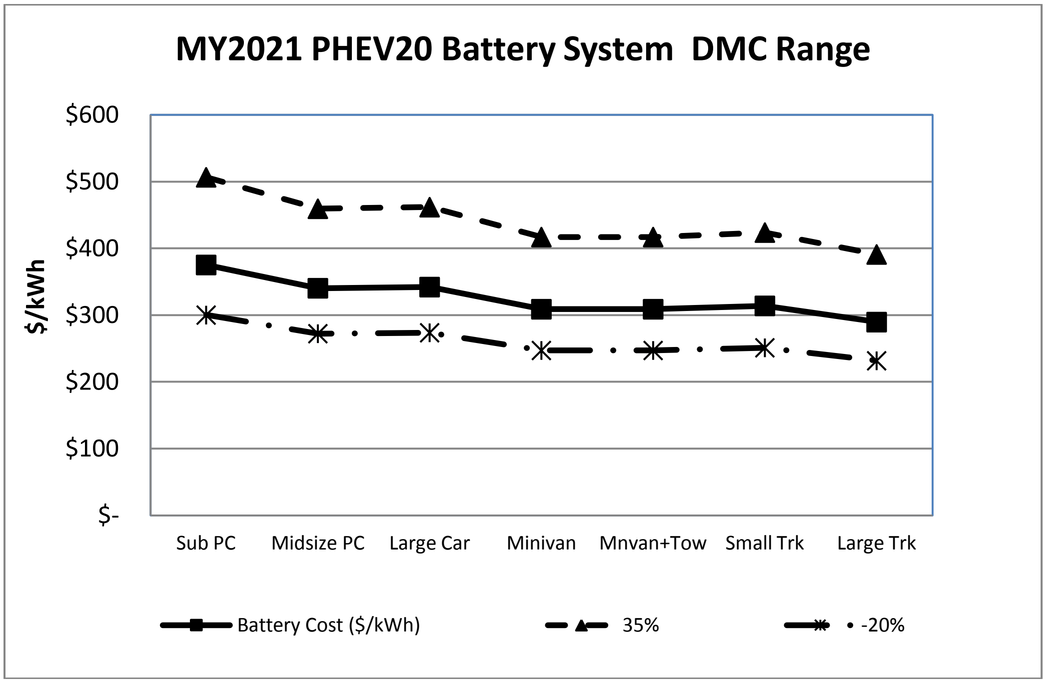


Figure X-3
Battery System Direct Manufacture Cost (DMC) for PHEV40

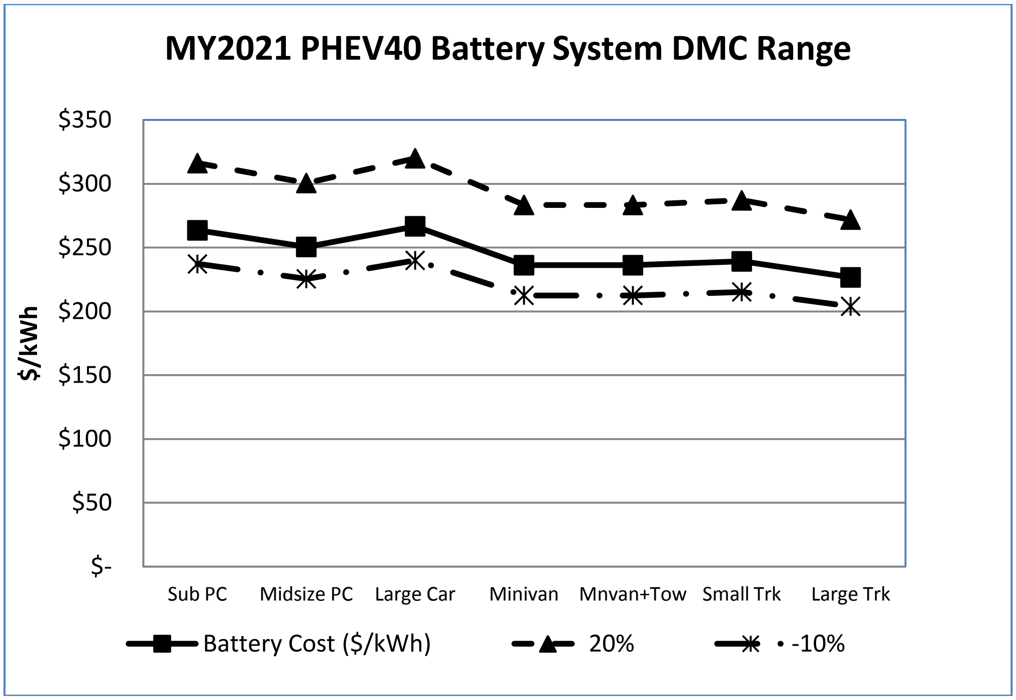


Figure X-4
Battery System Direct Manufacture Cost (DMC) for EV75

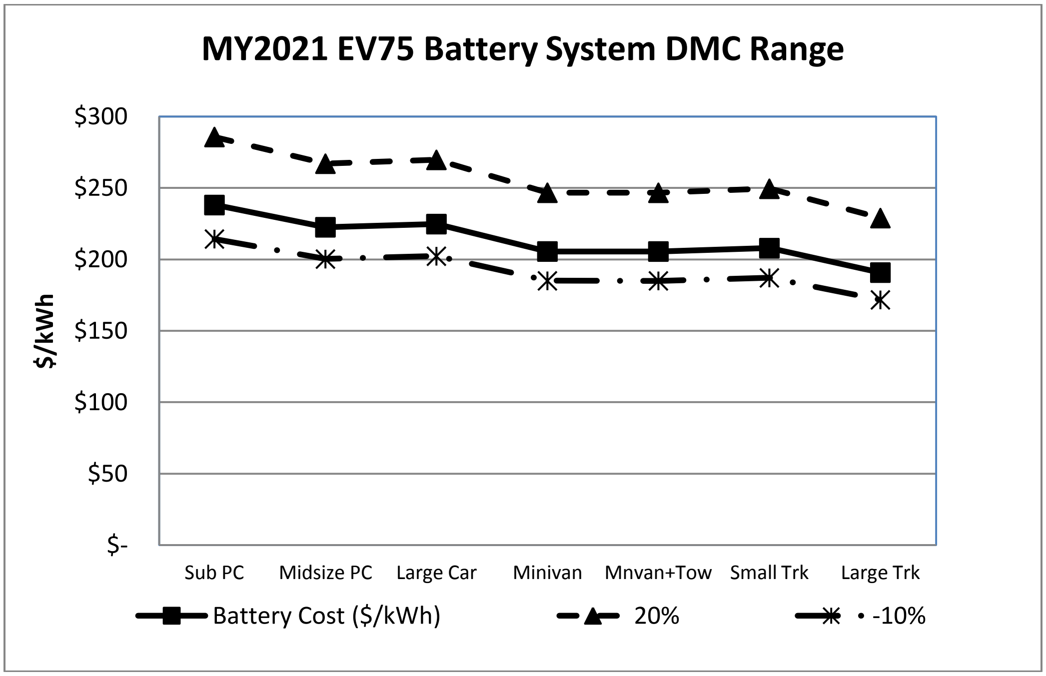
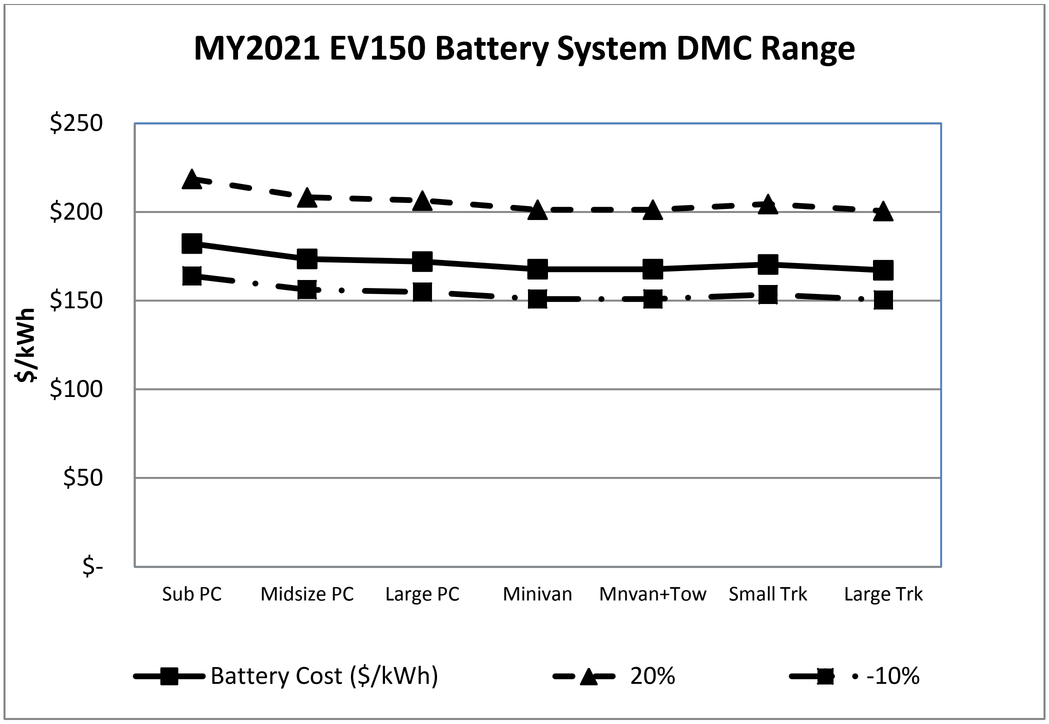


Figure X-5
Battery System Direct Manufacture Cost (DMC) for EV150



For the reader's reference, this sensitivity was conducted using what the agency refers to as "standard setting" analytical runs, in which the agency restricts the operation of the model consistent with statutory requirements related to how the agency may determine maximum feasible CAFE standards (for example, the standard setting runs do not include EVs, because NHTSA may not consider the fuel economy of EVs when setting maximum feasible CAFE standards, nor do they consider PHEVs prior to MY 2020, for the same reason), as compared to the "real-world" analysis, in which the agency attempts to model how manufacturers might respond to the proposed standards (and regulatory alternatives) taking account of all available technologies and compliance flexibilities. NHTSA used the "standard setting" runs for this sensitivity analysis to show the regulatory impact of the battery cost. In the "standard setting" runs, NHTSA included 30-mile range PHEV (PHEV30) only after MY2019 to represent all PHEVs, the cost of which is the average cost of PHEV20 and PHEV40. NHTSA did not apply any EVs in this analysis.

7) Mass reduction cost: Due to the wide range of mass reduction cost as stated in TSD Chapter 3, a sensitivity analysis was performed examining the impact of the cost of vehicle mass reduction to the total technology cost. The direct manufacturing cost (DMC) for mass reduction is represented as a linear function between the unit DMC versus percent of mass reduction as shown in Figure X-6. The slope of this line used for NPRM central analysis is $4.32 per pound per percent of mass reduction. The slope of the line is varied ± 40% as the

upper and lower bound for this sensitivity study. The values for the range of mass reduction cost are shown in Table X-10.

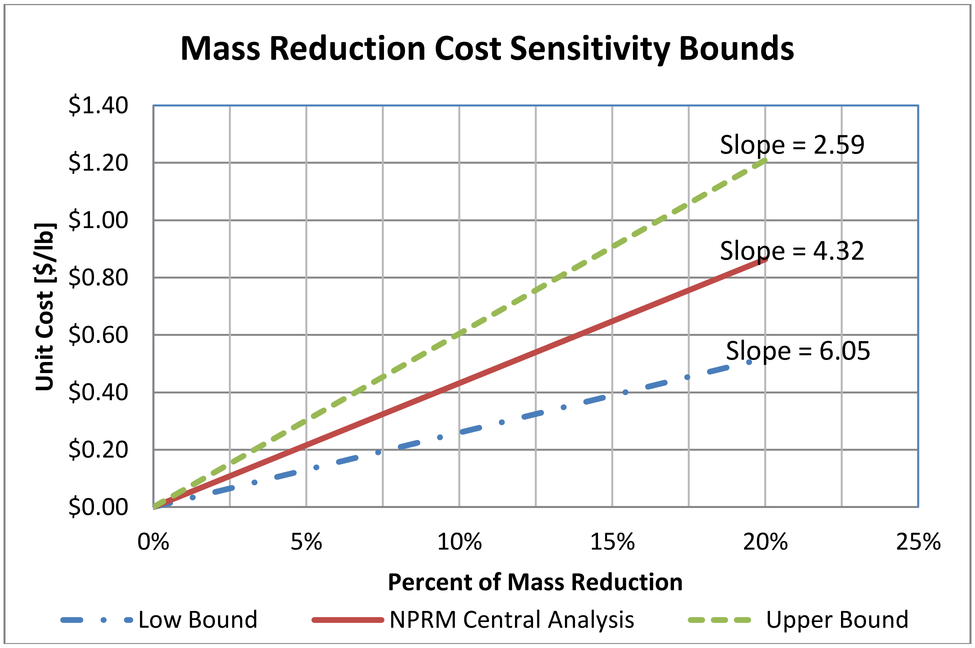
Table X-10
Bounds for Mass Reduction Direct Manufacturing Cost

Sensitivity Bound	**Slope of Mass Reduction Line [$/(lb-%MR)]**	**Example Unit Direct Manufacture Cost[1] [$/lb]**	**Example Total Direct Manufacture Cost[2] [$/lb]**
Lower Bound	$2.59	$0.39	$233
NPRM Central Analysis	$4.32	$0.65	$389
Upper Bound	$6.05	$0.91	$544

Notes

1. Example is based on 15% mass reduction.
   Unit direct manufacturing cost [$/lb]= Slope x Percent of Mass Reduction
2. Example is based on 15% mass reduction for a 4000-lb vehicle.
   Total direct manufacturing cost [$] = Unit Direct Manufacturing Cost x Amount of Mass Reduction

Figure X-6
Direct Manufacturing Cost for Mass Reduction



8) Market-driven response: The baseline for the central analysis is based on the MY 2016 CAFE standards and assumes that manufacturers will make no changes in the fuel economy from that level through MY 2025. A sensitivity analysis was performed to simulate potential increases in fuel economy over the compliance level required if MY 2016 standards were to

remain in place. The assumption is that the market would drive manufacturers to put technologies into their vehicles that they believe consumers would value and be willing to pay for. Using parameter values consistent with the central analysis, the agency simulated a market-driven response baseline by applying a payback period of one year for purposes of calculating the value of future fuel savings when simulating whether manufacturers would apply additional technology to an already CAFE-compliant fleet. In other words we assumed that manufacturers that were above their MY 2016 CAFE level would compare the cost to consumers to the fuel savings in the first year of operation and decide to voluntarily apply those technologies to their vehicles when benefits for the first year exceeded costs for the consumer. For a manufacturer's fleet that that has not yet achieved compliance with CAFE standards, the agency continued to apply a five-year payback period. In other words, for this sensitivity analysis the agency assumed that manufacturers that have not yet met CAFE standards for future model years will apply technology as if buyers were willing to pay for the technologies as long as the fuel savings throughout the first five years of vehicle ownership exceeded their costs. Once having complied with those standards, however, manufacturers are assumed to consider making further improvements in fuel economy as if buyers were only willing to pay for fuel savings to be realized during the first year of vehicle ownership. The 'market-drive response' analysis assumes manufacturers will overcomply if additional technology is sufficiently cost effective. Because this assumption has a greater impact under the baseline standards, its application reduces the incremental costs, effects, and benefits attributable to the new standards. This does not mean costs, effects, and benefits would actually be smaller with a market-driven response; rather it means costs, effects, and benefits would be at least as great, but would be partially attributable not to the new standards, but instead to the market.

Above we discuss how we mathematically determined market demand, but a potential rationale for more market demand follows: For years, consumers have been learning about the benefits that accrue to them from owning and operating vehicles with greater fuel efficiency. Consumer demand has thus shifted towards such vehicles, not only because of higher fuel prices but also because many consumers are learning about the value of purchases based not only on initial costs but also on the total cost of owning and operating a vehicle over its lifetime. This type of learning is expected to continue before and during the model years affected by this rule, particularly given the new fuel economy labels that clarify potential economic effects and should therefore reinforce that learning. Therefore, some increase in the demand for, and production of, more fuel efficient vehicles is incorporated as a market driven response in this sensitivity analysis. The agency requests comment on the appropriateness of using a flat or rising baseline after 2016.

Varying each of the above 8 parameters in isolation results in a variety of economic scenarios. These are listed in Table X-11 below along with the preferred alternative.

9) The agency performed two additional sensitivity analyses presented in Tables X-14 and X-15. First, the agency analyzed the impact that having a retail price equivalent (RPE) factor of 1.5 for all technologies would have on the various alternatives instead of using the indirect cost methodology (ICM). The ICM methodology results in an overall markup factor of 1.2 to 1.25 compared to the RPE markup factor from variable cost of 1.5. Next, the agency conducted a separate sensitivity analysis using values that were derived from the 2011 NAS

report.[2] This analysis used an RPE markup factor of 1.5 for non-electrification technologies, which is consistent with the NAS estimation for technologies manufactured by suppliers, and a RPE markup factor of 1.33 for electrification technologies (HEV, PHEV and EV); three types of learning which include no learning for mature technologies, 1.25 percent annual learning for evolutionary technologies, and 2.5 percent annual learning for revolutionary technologies; technology cost estimates for 52 percent (33 out of 63) technologies; and technology effectiveness estimates for 56 percent (35 out of 63) of technologies. Cost learning was applied to technology costs in a manner similar to how cost learning is applied in the central analysis for many technologies which have base costs which are applicable to recent or near-term future model years. As noted above, the cost learning factors used for the sensitivity case are different than the values used in the central analysis. For the other inputs in the sensitivity case, where the NAS study has inconsistent information or lacks projections, NHTSA is used the same input values that were used in the central analysis.

10) Table X-16 separately examines the sensitivity of the benefits of reducing criteria pollutants and vehicle safety to alternate values of statistical life.

Table X-11
Sensitivity Analyses

Name	**Fuel Price**	**Discount Rate**	**Rebound Effect**	**SCC**	**Military Security**
Reference	Reference	3%	10%	$22	0¢/ gal
High Fuel Price	High	3%	10%	$22	0¢/ gal
Low Fuel Price	Low	3%	10%	$22	0¢/ gal
5% Rebound Effect	Reference	3%	5%	$22	0¢/ gal
15% Rebound Effect	Reference	3%	15%	$22	0¢/ gal
20% Rebound Effect	Reference	3%	20%	$22	0¢/ gal
12¢/ gal Military Security Value	Reference	3%	10%	$22	12¢/ gal
$5/ ton CO_2 Value	Reference	3%	10%	$5	0¢/ gal
$36/ ton CO_2 Value	Reference	3%	10%	$36	0¢/ gal
$67/ ton CO_2 Value	Reference	3%	10%	$67	0¢/ gal
50% Consumer Benefit	Reference	3%	10%	$22	0¢/ gal
75% Consumer Benefit	Reference	3%	10%	$22	0¢/ gal
Low Battery Cost	Reference	3%	10%	$22	0¢/ gal
High Battery Cost	Reference	3%	10%	$22	0¢/ gal
Low Cost Mass Reduction	Reference	3%	10%	$22	0¢/ gal
High Cost Mass Reduction	Reference	3%	10%	$22	0¢/ gal
Market-Driven Response	Reference	3%	10%	$22	0¢/ gal

Table X-12 presents the achieved fuel economy, per-vehicle price increase, total benefits, total cost, lifetime fuel savings, and the lifetime reductions in CO_2 emissions that would result under the standards from the economic scenarios. For the achieved fuel economy and per-vehicle price increase, the table presents only the model year 2025 results, since this model year showed the greatest impacts. For net benefits, fuel savings, and CO_2 emissions reductions, the table presents totals over the nine model years, rather than their values for MY 2025, to reflect the total impact of the standards that would result from the various economic assumptions. To derive a valid comparison between the baseline and the sensitivity analyses, all runs were based on a 3% discount rate using the central standard setting data runs. Thus, the preferred mpg levels and baseline are slightly different than the main analysis. Costs include both technology costs and fine payments.

Table X-13 presents the percentage changes from the Preferred Alternative economic assumptions for the items in Table X-12. From these tables, we conclude the following regarding the impact of varying the economic parameters among the considered values:

1) Varying the economic assumptions has almost no impact on achieved mpg. The mass reduction cost sensitivities, battery cost reduction sensitivities, and the market-based baseline sensitivity are the only cases in which achieved mpg differs from the reference case of the Preferred Alternative. None of these alter the outcome by more than 0.2 mpg for either fleet.
2) Varying the economic assumptions has, at most, a small impact on per-vehicle costs, fuel saved, and CO_2 emissions reductions, with none of the variations impacting the outcomes by more than 10 percent from their central analysis levels, save for several exceptions including the alternate fuel price sensitivities and the 20 percent rebound effect sensitivity.
3) The category most affected by variations in the economic parameters considered in these sensitivity analyses is net benefits. The sensitivity analyses examining the AEO low and high fuel price scenarios demonstrate the potential to negatively impact net benefits by up to 40.3% or to increase net benefits by 29.5% relative to those of the Preferred Alternative. Other large impacts on net benefits occurred with the 20 percent rebound effect (-38.4%), valuing benefits at 50 and 75 percent (-63.0% and -31.5%, respectively), and valuing the reduction in CO_2 emissions at $67/ton (+28.1%).
4) Even if consumers value the benefits achieved at 50% of the main analysis assumptions, total benefits still exceed costs.

Regarding the lower fuel savings and CO_2 emissions reductions predicted by the sensitivity analysis as fuel price increases, which initially may seem counterintuitive, we note that there are some counterbalancing factors occurring. As fuel price increases, people will drive less and so fuel savings and CO_2 emissions reductions may decrease.

Table X-12a
Sensitivity Analyses
(mpg, Per-Vehicle Cost, Total Benefits, Total Cost, Fuel Saved, & CO_2 Emissions Reduced)
Passenger Cars

Economic Assumptions	**MY 2025 Achieved mpg**	**MY 2025 Per-Vehicle Cost**	**MY 2017-2025 Net Benefits, Discounted 3%, in Millions of $**	**MY 2017-2025 Fuel Saved, in Millions of Gallons**	**MY 2017-2025 CO2 Emissions Reduced, in mmT**
Passenger Cars					
Preferred	52.7	$2,023	$189,653	100,068	1059
High Fuel Price	52.7	$2,023	$106,231	111,458	1182
Low Fuel Price	52.7	$2,023	$251,612	87,637	925
5% Rebound Effect	52.7	$2,023	$230,719	108,435	1150
15% Rebound Effect	52.7	$2,023	$148,587	91,701	968
20% Rebound Effect	52.7	$2,023	$107,521	83,335	877
12¢/ gal Military Security Value	52.7	$2,023	$199,053	100,068	1059
$5/ ton CO2 Value	52.7	$2,023	$168,425	100,068	1059
$36/ ton CO2 Value	52.7	$2,023	$206,320	100,068	1059
$67/ ton CO2 Value	52.7	$2,023	$248,268	100,068	1059
50% Consumer Benefit	52.7	$2,023	$57,950	100,068	1059
75% Consumer Benefit	52.7	$2,023	$123,801	100,068	1059
Low Battery Cost	52.7	$2,007	$190,225	100,060	1059
High Battery Cost	52.6	$2,063	$188,082	99,960	1058
Low Cost Mass Reduction	52.8	$2,026	$190,839	99,673	1057
High Cost Mass Reduction	52.6	$2,083	$186,643	99,860	1059
Market-Driven Response	52.6	$2,036	$172,786	94,857	1006

Table X-12b
Sensitivity Analyses
(mpg, Per-Vehicle Cost, Total Benefits, Total Cost, Fuel Saved, & CO_2 Emissions Reduced)
Light Trucks

Economic Assumptions	**MY 2025 Achieved mpg**	**MY 2025 Per-Vehicle Cost**	**MY 2017-2025 Net Benefits, Discounted 3%, in Millions of $**	**MY 2017-2025 Fuel Saved, in Millions of Gallons**	**MY 2017-2025 CO2 Emissions Reduced, in mmT**
Light Trucks					
Preferred	39.6	$1,578	$160,738	69,087	729
High Fuel Price	39.6	$1,578	$103,089	77,246	817
Low Fuel Price	39.6	$1,578	$202,128	60,305	635
5% Rebound Effect	39.6	$1,578	$186,896	75,108	795
15% Rebound Effect	39.6	$1,578	$134,580	63,067	664
20% Rebound Effect	39.6	$1,578	$108,423	57,047	598
12¢/ gal Military Security Value	39.6	$1,578	$167,066	69,087	729
$5/ ton CO2 Value	39.6	$1,578	$146,230	69,087	729
$36/ ton CO2 Value	39.6	$1,578	$172,149	69,087	729
$67/ ton CO2 Value	39.6	$1,578	$200,683	69,087	729
50% Consumer Benefit	39.6	$1,578	$71,815	69,087	729
75% Consumer Benefit	39.6	$1,578	$116,277	69,087	729
Low Battery Cost	39.6	$1,578	$160,738	69,087	729
High Battery Cost	39.6	$1,578	$160,740	69,088	729
Low Cost Mass Reduction	39.8	$1,397	$167,391	69,577	737
High Cost Mass Reduction	39.5	$1,687	$158,382	68,990	728
Market-Driven Response	39.6	$1,532	$144,289	62,773	673

Table X-12c
Sensitivity Analyses
(mpg, Per-Vehicle Cost, Total Benefits, Total Cost, Fuel Saved, & CO_2 Emissions Reduced)
Passenger Cars and Light Trucks Combined

Economic Assumptions	MY 2025 Achieved mpg	MY 2025 Per-Vehicle Cost	MY 2017-2025 Net Benefits, Discounted 3%, in Millions of $	MY 2017-2025 Fuel Saved, in Millions of Gallons	MY 2017-2025 CO2 Emissions Reduced, in mmT
Passenger Cars and Light Trucks					
Preferred	47.5	$1,876	$350,391	169,156	1788
High Fuel Price	47.5	$1,876	$209,320	188,704	1999
Low Fuel Price	47.5	$1,876	$453,740	147,941	1560
5% Rebound Effect	47.5	$1,876	$417,615	183,542	1945
15% Rebound Effect	47.5	$1,876	$283,167	154,769	1632
20% Rebound Effect	47.5	$1,876	$215,944	140,382	1475
12¢/ gal Military Security Value	47.5	$1,876	$366,119	169,156	1788
$5/ ton CO2 Value	47.5	$1,876	$314,655	169,156	1788
$36/ ton CO2 Value	47.5	$1,876	$378,469	169,156	1788
$67/ ton CO2 Value	47.5	$1,876	$448,952	169,156	1788
50% Consumer Benefit	47.5	$1,876	$129,765	169,156	1788
75% Consumer Benefit	47.5	$1,876	$240,078	169,156	1788
Low Battery Cost	47.5	$1,865	$350,964	169,148	1788
High Battery Cost	47.5	$1,902	$348,822	169,048	1787
Low Cost Mass Reduction	47.6	$1,817	$358,230	169,251	1794
High Cost Mass Reduction	47.4	$1,952	$345,025	168,850	1788
Market-Driven Response	47.5	$1,869	$317,075	157,630	1679

Table X-13a
Sensitivity Analyses – Percentage Change from the Reference Case
Passenger Cars

Economic Assumptions	MY 2025 Achieved mpg	MY 2025 Per-Vehicle Cost	MY 2017-2025 Net Benefits, Discounted 3%, in Millions of $	MY 2017-2025 Fuel Saved, in Millions of Gallons	MY 2017-2025 CO2 Emissions Reduced, in mmT
Passenger Cars					
Preferred	Base	Base	Base	Base	Base
High Fuel Price	0.0%	0.0%	-44.0%	11.4%	11.6%
Low Fuel Price	0.0%	0.0%	32.7%	-12.4%	-12.6%
5% Rebound Effect	0.0%	0.0%	21.7%	8.4%	8.6%
15% Rebound Effect	0.0%	0.0%	-21.7%	-8.4%	-8.6%
20% Rebound Effect	0.0%	0.0%	-43.3%	-16.7%	-17.2%
12¢/ gal Military Security Value	0.0%	0.0%	5.0%	0.0%	0.0%
$5/ ton CO2 Value	0.0%	0.0%	-11.2%	0.0%	0.0%
$36/ ton CO2 Value	0.0%	0.0%	8.8%	0.0%	0.0%
$67/ ton CO2 Value	0.0%	0.0%	30.9%	0.0%	0.0%
50% Consumer Benefit	0.0%	0.0%	-69.4%	0.0%	0.0%
75% Consumer Benefit	0.0%	0.0%	-34.7%	0.0%	0.0%
Low Battery Cost	0.1%	-0.8%	0.3%	0.0%	0.0%
High Battery Cost	-0.1%	2.0%	-0.8%	-0.1%	-0.1%
Low Cost Mass Reduction	0.2%	0.1%	0.6%	-0.4%	-0.2%
High Cost Mass Reduction	-0.2%	3.0%	-1.6%	-0.2%	0.0%
Market-Driven Response	-0.1%	0.6%	-8.9%	-5.2%	-5.0%

Table X-13b
Sensitivity Analyses – Percentage Change from the Reference Case
Light Trucks

Economic Assumptions	**MY 2025 Achieved mpg**	**MY 2025 Per-Vehicle Cost**	**MY 2017-2025 Net Benefits, Discounted 3%, in Millions of $**	**MY 2017-2025 Fuel Saved, in Millions of Gallons**	**MY 2017-2025 CO2 Emissions Reduced, in mmT**
Light Trucks					
Preferred	Base	Base	Base	Base	Base
High Fuel Price	0.0%	0.0%	-35.9%	11.8%	12.0%
Low Fuel Price	0.0%	0.0%	25.7%	-12.7%	-12.9%
5% Rebound Effect	0.0%	0.0%	16.3%	8.7%	9.0%
15% Rebound Effect	0.0%	0.0%	-16.3%	-8.7%	-9.0%
20% Rebound Effect	0.0%	0.0%	-32.5%	-17.4%	-17.9%
12¢/ gal Military Security Value	0.0%	0.0%	3.9%	0.0%	0.0%
$5/ ton CO2 Value	0.0%	0.0%	-9.0%	0.0%	0.0%
$36/ ton CO2 Value	0.0%	0.0%	7.1%	0.0%	0.0%
$67/ ton CO2 Value	0.0%	0.0%	24.9%	0.0%	0.0%
50% Consumer Benefit	0.0%	0.0%	-55.3%	0.0%	0.0%
75% Consumer Benefit	0.0%	0.0%	-27.7%	0.0%	0.0%
Low Battery Cost	0.0%	0.0%	0.0%	0.0%	0.0%
High Battery Cost	0.0%	0.0%	0.0%	0.0%	0.0%
Low Cost Mass Reduction	0.4%	-11.5%	4.1%	0.7%	1.0%
High Cost Mass Reduction	-0.3%	6.9%	-1.5%	-0.1%	-0.1%
Market-Driven Response	0.0%	-2.9%	-10.2%	-9.1%	-7.7%

Table X-13c
Sensitivity Analyses – Percentage Change from the Reference Case
Passenger Cars and Light Trucks Combined

Economic Assumptions	MY 2025 Achieved mpg	MY 2025 Per-Vehicle Cost	MY 2017-2025 Net Benefits, Discounted 3%, in Millions of $	MY 2017-2025 Fuel Saved, in Millions of Gallons	MY 2017-2025 CO2 Emissions Reduced, in mmT
Passenger Cars and Light Trucks					
Preferred	Base	Base	Base	Base	Base
High Fuel Price	0.0%	0.0%	-40.3%	11.6%	11.8%
Low Fuel Price	0.0%	0.0%	29.5%	-12.5%	-12.8%
5% Rebound Effect	0.0%	0.0%	19.2%	8.5%	8.8%
15% Rebound Effect	0.0%	0.0%	-19.2%	-8.5%	-8.8%
20% Rebound Effect	0.0%	0.0%	-38.4%	-17.0%	-17.5%
12¢/ gal Military Security Value	0.0%	0.0%	4.5%	0.0%	0.0%
$5/ ton CO2 Value	0.0%	0.0%	-10.2%	0.0%	0.0%
$36/ ton CO2 Value	0.0%	0.0%	8.0%	0.0%	0.0%
$67/ ton CO2 Value	0.0%	0.0%	28.1%	0.0%	0.0%
50% Consumer Benefit	0.0%	0.0%	-63.0%	0.0%	0.0%
75% Consumer Benefit	0.0%	0.0%	-31.5%	0.0%	0.0%
Low Battery Cost	0.0%	-0.6%	0.2%	0.0%	0.0%
High Battery Cost	-0.1%	1.4%	-0.4%	-0.1%	-0.1%
Low Cost Mass Reduction	0.3%	-3.1%	2.2%	0.1%	0.3%
High Cost Mass Reduction	-0.3%	4.1%	-1.5%	-0.2%	0.0%
Market-Driven Response	-0.1%	-0.3%	-9.5%	-6.8%	-6.1%

Table X-14a
Achieved mpg level, MY 2025
Comparing Different Cost Mark-up Methodologies
(3% Discount Rate)

	ICM Method (Main Analysis Costs)	RPE Method (Main Analysis Costs)	Difference (mpg)
Passenger Cars			
Preferred Alternative	52.70	52.24	0.46
Max Net Benefits	49.09	48.47	0.61
Light trucks			
Preferred Alternative	39.59	39.38	0.21
Max Net Benefits	44.31	44.17	0.14

Table X-14b
Achieved mpg level, MY 2025
Comparing ICM Method with Main Analysis Costs vs. NAS Costs
(3% Discount Rate)

	ICM Method (Main Analysis Costs)	ICM Method (NAS Cost Estimates)	Difference (mpg)
Passenger Cars			
Preferred Alternative	52.70	52.11	0.59
Max Net Benefits	49.09	48.28	0.80
Light trucks			
Preferred Alternative	39.59	39.08	0.51
Max Net Benefits	44.31	44.48	-0.18

Table X-15
Sensitivity Analyses
(Achieved mpg, Per-Vehicle Cost, Net Benefits, Fuel Saved, & CO_2 Emissions Reduced)

Cost Method and Set of Cost Estimates	MY 2025 Achieved mpg	Average MY 2025 Per-Vehicle Technology Cost	MY 2017-2025 Net Benefits, Discounted 3%, in Millions of $	MY 2017-2025 Fuel Saved, in Millions of Gallons	MY 2017-2025 CO2 Emissions Reduced, in mmT
Passenger Cars					
ICM w/ Main Analysis Costs	52.70	$2,023	$189,653	100,068	1,059
RPE w/ Main Analysis Costs	52.24	$2,509	$163,601	100,708	1,062
ICM w/ NAS Costs	52.11	$2,811	$148,586	101,385	1,074
Light trucks					
ICM w/ Main Analysis Costs	39.59	$1,578	$160,738	69,087	729
RPE w/ Main Analysis Costs	39.38	$2,038	$148,310	68,241	722
ICM w/ NAS Costs	39.08	$2,405	$138,715	66,339	724

Sensitivity Analysis, Value of Statistical Life

The value associated with preventing a fatality is measured by the Value of a Statistical Life (VSL), defined as the value of preventing one random fatality among a population at risk. The Office of Management and Budget (OMB) reviews and approves regulations issued from numerous agencies including DOT, EPA, OSHA, CPSC, etc., and issues guidance for agencies to use in analyzing the impacts of their regulations. Although OMB guidance generally seeks to ensure a level of consistency in the issues addressed by various regulatory agencies, OMB has not established a common VSL for use across all government agencies. Instead, OMB recommends that each agency develop and justify its own VSL. As a result, different agencies assign different values to saving a life in their regulations.

The Department of Transportation (DOT) has issued a series of guidance memos for the various modes within the department. In February 2008, DOT established a VSL of $5.8 million with supplementary calculations at $3.2 million and $8.4 million in recognition of uncertainty found over a range of studies (these figures are measured in 2007 dollars). NHTSA typically adds the economic cost of crashes to the VSL of about $300,000 to determine the comprehensive cost of fatal crashes. These economic costs include medical costs, legal costs, insurance administration costs, property damage, travel delay costs, etc. Bringing these numbers up to 2009 economics results in a VSL of $6.0 million, comprehensive costs of $6.32 million for the central analysis, and supplemental comprehensive costs of $3.72 and $8.92 million.

Within the CAFE PRIA, VSL is used for two different purposes, once to value benefits-per-ton from reducing emissions of criteria pollutants in Chapter VIII, and once to value potential safety impacts in Chapter IX. The potential safety impacts calculation is discussed outside the Volpe model, in order to emphasize the uncertainty surrounding this issue. It is examined separately and put in context of the overall net benefits derived from the Volpe model.

The benefits-per-ton values for reducing emissions of criteria pollutants were derived by EPA for use by both EPA and NHTSA in this rulemaking activity. These estimates were based on an estimate of VSL derived previously by EPA and reported in its *Guidelines for Preparing Economic Analyses* (see Technical Support Document, Section 4.B.11.b.).[417] This estimate is $6.3 million in 2000 dollars, which corresponds to $7.79 million when expressed in 2009 dollars. NHTSA agreed to use the estimates of per-ton benefits from reducing air pollutant emissions derived by EPA in this rulemaking, despite their reliance on a VSL estimate higher than that endorsed by DOT.

As noted in the DOT guidance, however, the uncertainty surrounding the VSL is notable, and should be recognized in regulatory analyses. Accordingly, NHTSA has prepared this sensitivity analysis, which examines the values of both safety mortality impact and mortality benefits from reducing criteria pollutant emissions under the complete range of DOT VSL values, as well as the EPA value. Table X-16 summarizes these estimates:

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[417] 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 at* http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/cover.pdf (last accessed March 4,2010).

Table X-16
Sensitivity Analysis of Alternate VSLs
Preferred Alternative
Combining MY 2017 through MY 2025

Assumed VSL (2009 Dollars)	Source	Value of Fatality Impacts ($millions)	Value of Mortality Benefits from Reduced Emissions of Criteria Air Pollutants ($millions)
$3.72 million	DOT Lower Estimate	$106 savings	$464
$6.32 million	DOT Central Estimate	$180 savings	$789
$7.79 million	EPA Estimate	$227 savings	$942
$8.92 million	DOT Upper Estimate	$254 savings	$1,113

As mentioned above, the safety impacts are highly uncertain and are not used in the Volpe model. Although the criteria pollutants benefits are used in the Volpe model, their impact is small.

Sensitivity Analysis for Maximum Net Benefit and Total Costs = Total Benefits Alternatives

In the tables above, the preferred alternative is the baseline and sensitivity analyses are compared to the preferred alternative. For the maximum net benefits and total cost = total benefit alternatives, it is more likely that the mpg level will be more affected by different assumptions that affect costs and benefits, due to the methodology used to determine the mpg level of those alternatives. Thus, this analysis compares MY 2025 passenger car, light truck and combined mpg levels for different sensitivity analyses (see Tables X-17a and X-17b) at a 3% discount rate.

Table X-17a
Sensitivity Analysis for Maximum Net Benefits Alternative

Maximum Net Benefit	**Passenger Car mpg**	**Light Truck mpg**	**Combined mpg**
Reference	49.1	44.3	47.4
7% Discount Rate	49.1	40.5	45.9
High Fuel Price	49.1	44.3	47.4
Low Fuel Price	49.1	44.3	47.4
5% Rebound Effect	49.1	44.3	47.4
15% Rebound Effect	49.1	44.3	47.4
20% Rebound Effect	49.1	44.3	47.4
12¢/ gal Military Security Value	49.1	44.3	47.4
$5/ ton CO2 Value	49.1	44.3	47.4
$36/ ton CO2 Value	49.1	44.3	47.4
$67/ ton CO2 Value	49.1	44.3	47.4
50% Consumer Benefit	49.1	44.3	47.4
75% Consumer Benefit	49.1	44.3	47.4
Low Battery Cost	49.1	44.3	47.4
High Battery Cost	49.0	44.3	47.4
Low Cost Mass Reduction	49.0	44.7	47.5
High Cost Mass Reduction	49.0	44.3	47.3
RPE w/ Main Analysis Costs	48.5	44.2	47.0
ICM w/ NAS Costs	48.3	44.5	47.0
Market-Driven Response	49.1	44.5	47.5

Table X-17b
Sensitivity Analysis for Total Cost = Total Benefit Alternative

Maximum Net Benefit	**Passenger Car mpg**	**Light Truck mpg**	**Combined mpg**
Reference	54.2	44.4	50.5
7% Discount Rate	54.2	44.4	50.5
High Fuel Price	54.2	44.4	50.5
Low Fuel Price	54.2	44.4	50.5
5% Rebound Effect	54.2	44.4	50.5
15% Rebound Effect	54.2	44.4	50.5
20% Rebound Effect	54.2	44.4	50.5
12¢/ gal Military Security Value	54.2	44.4	50.5
$5/ ton CO2 Value	54.2	44.4	50.5
$36/ ton CO2 Value	54.2	44.4	50.5
$67/ ton CO2 Value	54.2	44.4	50.5
50% Consumer Benefit	54.2	44.4	50.5
75% Consumer Benefit	54.2	44.4	50.5
Low Battery Cost	54.3	44.4	50.5
High Battery Cost	54.2	44.3	50.5
Low Cost Mass Reduction	54.3	44.7	50.7
High Cost Mass Reduction	54.1	44.4	50.5
RPE w/ Main Analysis Costs	53.3	44.1	49.9
ICM w/ NAS Costs	53.9	44.5	50.4
Market-Driven Response	54.2	44.8	50.7

XI. FLEXIBILITIES IN MEETING THE STANDARD

The Energy Policy and Conservation Act (EPCA) requires DOT to provide several specific flexibilities with respect to compliance with CAFE standards. These CAFE credit provisions govern the use of Alternative Motor Fuels Act (AMFA) credits for dedicated and dual-fueled alternative fuel vehicles, the use of credit carry-forward and carry-back provisions, credit transfers between a manufacturer's fleets, and credit trades among different manufacturers. Because EPCA prohibits NHTSA from considering these statutorily-established flexibilities when determining the stringency of CAFE standards, NHTSA did not consider these flexibilities when it developed alternatives for this rulemaking. EPCA also requires NHTSA to levy civil penalties on manufacturers that fail to achieve CAFE standards (or to apply sufficient CAFE credits to offset any shortfall). EPCA does not prohibit NHTSA from considering this provision when determining the stringency of CAFE standards; thus, as for all recent CAFE rulemakings, NHTSA's analysis has accounted for the potential that some manufacturers would elect to pay civil penalties rather than achieving compliance with CAFE standards.

Additionally, for this proposal, EPA, in coordination with NHTSA, is proposing under its EPCA authority to allow manufacturers to generate fuel consumption improvement values for purposes of CAFE compliance based on the use of A/C efficiency technologies, off-cycle technologies, and for manufacturers that hybridize a significant quantity of their full-size pickup trucks, or that use other technologies that significantly reduce fuel consumption for full-size pickup trucks. Because of the significant amount of credits and fuel consumption improvement values offered under the A/C program (up to 0.000563 gal/mi for cars and 0.000586 gal/mi for trucks), NHTSA believes that manufacturers will maximize the benefits these fuel consumption improvement values afford. The off-cycle technologies and advanced technology full-size pickup incentives are also expected to be heavily relied on, but it is more difficult for the agencies to quantify at this time the precise extent to which we expect manufacturers to do so. These incentives are discussed in more detail in Section II.F of the NPRM and in Chapter 5 of the draft Joint TSD, and we refer readers there for additional information regarding the value of the incentives and how they can be obtained.

NHTSA has considered these changes to calculation methods in our determination of the proposed standards.[418] As discussed in Section IV.F of the preamble, the agency accounted for EPA-estimated manufacturers' average application of A/C efficiency improvements, and correspondingly adjusted upward the CAFE standards that the agency would have proposed if EPA was not also proposing to include these A/C-related adjustments to fuel economy calculation methods. NHTSA did not, however, further adjust CAFE standards to account for the other EPA-proposed adjustments discussed above, based on the agencies' current inability to reasonably estimate the extent to which manufacturers will rely on those.

These incentives are likely to affect the actual costs, effects, and benefits of the proposed standards. For a given set of CAFE standards, each of the above incentives has to potential to

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[418] NHTSA interprets EPCA/EISA as allowing the agency to consider those flexibilities not established by statute in determining the maximum feasible CAFE standards.

make it less expensive for a given manufacturer to achieve compliance than if the mathematical functions defining the CAFE standards were the same yet the incentive was not provided. For the A/C and other off-cycle efficiency adjustments, while a manufacturer's corresponding actions would change *how* fuel savings are realized for a given fleet (passenger car or light trucks) in a given model year, the *amount* of fuel savings should remain virtually unchanged. For example, a manufacturer's application of active grille shutters on a given vehicle model might produce fuel savings at speeds beyond those observed on the highway test used in measuring fuel economy; the adjustment reflecting these improvements would make it possible for the vehicle to achieve a given fuel economy rating (for compliance purposes) without applying some other fuel-saving technology. However, insofar as the amount of the adjustment accurately reflects the magnitude of the fuel saved, net energy and environmental outcomes should be virtually unchanged.

Conversely, some of these incentives lead to reduced fuel savings and environmental benefits. CAFE credits provided based on the production of certain types of dual-fueled vehicles can do so, because the amount of credit can reflect greater use of the alternative fuel than typically occurs – this is generally true for dual-fueled gasoline/E85-capable vehicles, for example, although the opposite could be true for plug-in hybrid electric vehicles (PHEVs). The proposed adjustments for producing large numbers of pickups with strong hybrid-electric powertrains or fuel economy levels well above applicable footprint-based targets are likely to also involve some reduction of achieved CAFE levels and corresponding fuel savings and environmental benefits, because the adjustments increase calculated CAFE levels (*i.e.*, those used for compliance purposes) by more than the actual improvement in fuel economy achieved due to the application of those technologies on those vehicles.

The other remaining mechanisms—EPCA provisions allowing manufacturers to transfer CAFE credits between fleets and model years, and trade CAFE credits—cause fuel economy improvements and corresponding effects to be shifted between fleets and model years, but should not reduce overall long-term fuel savings and environmental benefits.[419]

NHTSA's central analysis of the effects of the proposed standards (and other evaluated regulatory alternatives) – that is, the fuel economy levels that we expect individual manufacturers to achieve, and the corresponding incremental technology outlays and average per-vehicle cost increases to meet those levels, along with corresponding fuel savings CO_2 emissions reductions – accounts for A/C-related adjustments to fuel economy levels (by adjusting manufacturers' estimated achieved CAFE levels and technology costs upward by amounts corresponding to the estimated average amount of earned adjustment), and for the potential that some vehicle manufacturers could elect to pay civil penalties (by assuming that those manufacturers cease to apply fuel-saving technology at the point where paying civil penalties becomes more cost-effective). Using recently-expanded capabilities of the CAFE modeling system, the agency has also conducted additional separate analysis to evaluate the combined effects of all of the following provisions: CAFE credits for producing FFVs, carry

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[419] NHTSA has structured the CAFE credit transfer and trading program to preserve total oil savings during transfers and trades by applying an "adjustment factor" whenever traded or transferred credits are used for compliance. *See* 49 CFR 536.4.

forward of CAFE credits between model years, and CAFE credit transfers between the passenger car and light truck fleets. For this analysis, the agency also included electric vehicles (EVs) and early plug-in hybrid electric vehicles (PHEVs) as available technologies. EPCA prohibits NHTSA from considering EVs and pre-MY 2020 PHEVs[420] when determining the stringency of future CAFE standards, so we do not consider them in our central analysis, but we expect manufacturers to employ these technologies, so it is still useful to evaluate the effect of these technologies; we also discuss key results of this side analysis above in Section IV.G of the NPRM.

The analysis, fleet-wide results of which are summarized below in Table XI-1, indicates that use of these incentive and flexibility provisions could (a) reduce the average achieved fuel economy by 0.5 mpg in MY 2025, and by 0.6-0.9 mpg in earlier model years, (b) reduce technology outlays by about $20 billion (13%) through MY 2025, (c) reduce average price increases by $38-$217 during MY 2017-2025, (d) reduce fuel saved through MY 2025 by about 8 billion gallons (5%), and (e) reduce CO_2 emissions avoided through MY 2025 by 85 mmt (5%).[421]

Table XI-1
Estimated Potential Impact of AFVs and Flexibilities
Preferred Alternative

	Earlier	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Average Achieved Fuel Economy (mpg)											
central analysis		35.2	36.9	38.8	40.4	42.3	43.4	44.6	46.1	47.4	
with flexibilities		34.5	36.0	38.0	39.7	41.5	42.5	43.9	45.3	46.9	
difference		(0.7)	(0.9)	(0.8)	(0.7)	(0.8)	(0.9)	(0.6)	(0.8)	(0.5)	
Total Incremental Technology Outlays ($b)											
central analysis	4	3	6	9	13	17	20	24	30	32	158
with flexibilities	2	2	4	8	11	15	17	22	26	29	137
difference	(2)	(1)	(1)	(1)	(2)	(2)	(3)	(2)	(4)	(3)	(20)
Average Price Increases ($)											
central analysis		175	389	596	840	1,127	1,285	1,531	1,840	1,975	
with flexibilities		136	300	517	743	988	1,119	1,406	1,623	1,793	
difference		(38)	(88)	(78)	(97)	(139)	(166)	(125)	(217)	(182)	
Fuel Savings (billion gallons)											
central analysis	4	3	7	11	15	19	21	24	27	30	160
with flexibilities	4	3	6	10	14	18	20	23	26	30	152
difference	0	0	(1)	(1)	(1)	(1)	(2)	(1)	(1)	(0)	(8)
Avoided CO_2 (million metric tons)											
central analysis	44	29	71	117	157	202	229	256	290	319	1,715

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[420] *See* discussion in Section IV.D of the preamble for NHTSA's legal position on this issue.

[421] Estimated differences in costs and prices do not include incremental costs to produce FFVs. The agency has previously estimated that modifications involved in enabling a gasoline vehicle to operate on E85 cost about $100-$175 (Final Regulatory Impact Analysis for MY2012-2016 final rule, March 2010, p. 575).

with flexibilities	45	30	61	110	148	189	213	246	277	312	1,631
difference	1	0	(10)	(7)	(9)	(13)	(17)	(10)	(13)	(7)	(85)

The CAFE model has not yet been updated to explicitly estimate the extent to which manufacturers might utilize the proposed average fuel economy calculation adjustments for manufacturers selling qualifying (as discussed above) full-size pickups. While DOT hopes to be able to do so in preparation for analysis to support a final rule, the agency has not determined how best to address some of the related analytical complexities. We have, however, made provisional estimates of the adjustments' potential impacts by estimating the potential magnitude of the adjustment to light truck CAFE levels among manufacturers of full-size pickups, and, for modeling purposes, treating these as CAFE credits. These estimates, summarized below in Table XI-2, are based, in turn, on estimated CAFE levels under the preferred alternative and then made the following estimates about hybrid technology application rates that seemed reasonable fleet-wide in response to the incentive that the flexibility provides.

Table XI-2
Estimates of Potential Hybrid Application Rates for Analyzing Effect of Full-Size Pickup Incentive

	MY 2017	MY 2018	MY 2019	MY 2020	MY 2021	MY 2022	MY 2023	MY 2024	MY 2025
Mild Hybrid	15%	20%	25%	33%	40%	0%	0%	0%	0%
Strong Hybrid	2%	4%	6%	8%	10%	13%	15%	18%	20%

In all, we estimate that these adjustments could increase reported CAFE levels (*i.e.*, CAFE levels reported for purposes of determining compliance) by 0.03-0.32 mpg, varying by manufacturer and model year:

Table XI-3
Estimated Potential Adjustments (mpg) to Light Truck CAFE Levels Due to Full-Size Pickup Incentive

	2017	2018	2019	2020	2021	2022	2023	2024	2025
Chrysler/Fiat	0.03	0.05	0.06	0.09	0.12	0.05	0.07	0.08	0.10
Ford	0.08	0.12	0.16	0.23	0.32	0.14	0.19	0.23	0.29
General Motors	0.06	0.09	0.12	0.16	0.21	0.09	0.11	0.14	0.18
Nissan	0.04	0.05	0.07	0.10	0.13	0.06	0.07	0.09	0.11
Toyota	0.03	0.05	0.06	0.08	0.12	0.05	0.07	0.08	0.10

Table XI-4 shows the estimated fleetwide impact of these adjustments on achieved CAFE levels, and compares these results to those shown above in Table XI-1 for the analysis that account for EVs, post-MY 2019 PHEVs, and other program flexibilities (but not including the proposed full-size pickup incentive). Reductions in estimated average achieved CAFE levels, incremental average technology outlays and price increases, and cumulative fuel savings and avoided CO_2 emissions are all smaller than one percent.[422]

Table XI-4
Estimated Potential Impact of Full-Size Pickup Incentive

	Earlier	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total
Average Achieved Fuel Economy (mpg)											
w/o adjustments		34.5	36.0	38.0	39.7	41.5	42.5	43.9	45.3	46.9	
with adjustments		34.5	36.0	38.0	39.7	41.4	42.4	43.8	45.3	46.8	
difference		(0.0)	0.0	(0.0)	(0.0)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	
Total Incremental Technology Outlays ($b)											
w/o adjustments	2	2	4	8	11	15	17	22	26	29	137
with adjustments	1	2	4	8	11	15	17	22	26	29	136
difference	(0)	(0)	0	(0)	(0)	(0)	(0)	(0)	0	(0)	(1)
Average Price Increases ($)											
w/o adjustments		136	300	517	743	988	1,119	1,406	1,623	1,793	
with adjustments		131	301	515	737	977	1,106	1,395	1,635	1,781	
difference		(5)	0	(2)	(6)	(11)	(13)	(11)	12	(12)	
Fuel Savings (billion gallons)											
w/o adjustments	4	3	6	10	14	18	20	23	26	30	153
with adjustments	4	3	6	10	14	17	20	23	26	29	151
difference	(0)	(0)	0	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)
Avoided CO_2 (million metric tons)											
w/o adjustments	45	30	61	110	148	189	213	246	277	312	1,631
with adjustments	43	29	62	110	147	187	210	243	276	310	1,617
difference	(2)	(1)	1	(0)	(1)	(2)	(2)	(3)	(1)	(3)	(14)

As mentioned above, the agency has not yet developed a satisfactory methodology for explicitly simulating the effects of these flexibilities. The results presented here result from an effort to account for the proposed adjustments by treating them similarly to FFV credits. This approach may have caused the model to produce results more consistent with the mechanism by which FFV credits operate than with the mechanism by which the proposed adjustments would operate. We anticipate that developing a more accurate methodology would pose a significant technical challenge, but time permitting, we will be attempting to develop one for the final rule. We invite comment on the plausibility of these provisional estimates of the adjustments' effects, and on possible methods to better estimate these effects. The agency's consideration of proposed methods will be facilitated by specific suggestions regarding integration into the CAFE model. For example, considering that the manufacturer must choose between the technology-based adjustment and the performance-based adjustment, how should the model simulate this choice? Also, considering that amount of adjustment is subject to volume limitations, how should the

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[422] Because of multiyear planning effects, some differences—also very small—begin accruing prior to MY2017, even though the proposed adjustments would not available until MY2017.

model simulate the manufacturer’s decision to concentrate technology on some specific vehicle models?

XII. PROBABILISTIC UNCERTAINTY ANALYSIS

OMB Circular A-4 requires formal probabilistic uncertainty analysis of complex rules where there are large, multiple uncertainties whose analysis raises technical challenges or where effects cascade and where the impacts of the rule exceed $1 billion. CAFE meets all of these criteria. This chapter identifies and quantifies the major uncertainties in the preliminary regulatory impact analysis and estimates the probability distribution of the benefits, costs, and net benefits of the compliance options selected for the proposed rule for MY 2017-2025 passenger car and light truck CAFE standards. Throughout the course of the main analysis, input values were selected from a variety of often conflicting sources. Best estimates were selected based on the preponderance of data and analyses available, but there is inevitably a level of uncertainty in these selections. Some of these inputs contributed less to the overall variations of the outcomes, and, thus, are less significant. Some inputs depend on others or are closely related (*e.g.*, oil import externalities), and thus can be combined. With the vast number of uncertainties embedded in this regulatory analysis, this uncertainty analysis identifies only the major independent uncertainty factors having appreciable variability and impact on the end results and quantifies them by their probability distributions. These newly defined values are then randomly selected and fed back into the model to determine the net benefits using the Monte Carlo statistical simulation technique.[423] The simulation technique induces the probabilistic outcomes accompanied with degrees of probability or plausibility. This facilitates a more informed decision-making process.

The analysis is based on the actual processes used to derive net benefits as described in the previous chapters. Each variable (*e.g.*, cost of technology) in the mathematical model represents an uncertainty factor that would potentially alter the modeling outcomes if its value was changed. We assume that these variables are independent of each other. The confidence intervals around the costs and benefits of technologies reflect independent levels of uncertainty regarding costs and benefits, rather than linked probabilities dependent on higher or lower quality versions of a specific technology.

The uncertainties of these variables are described by appropriate probability distribution functions based on available data. If data are not sufficient or not available, professional judgments are used to estimate the probability distributions of these uncertainty factors. A complete description of the formulas and methods used in the CAFE model is available in the public docket.[424]

After defining and quantifying the major uncertainty factors, the next step is to simulate the model to obtain probabilistic results rather than single-value estimates. In the uncertainty analysis, CAFE levels were kept constant; in other words, we did not change the CAFE standards for each run based on net benefits. The simulation process was run repeatedly for approximately 25,000 trials under each discount rate scenario, and separately for passenger car

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[423] See, for example, Morgan, MG, Henrion, M, and Small M, “Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis,” Cambridge University Press, 1990.

[424] CAFE Compliance and Effects Modeling System Documentation, Volpe Center, U.S. Dept. of Transportation, July 2005, pp. 27-46 and C-22 to C-35. *Available at* http://www.nhtsa.dot.gov (last accessed March 4, 2010).

and light truck fleets. Each complete run is a trial. For each trial, the simulation first randomly selects a value for each of the uncertainty factors based on their probability distributions. The selected values are then fit into the models to forecast results. In addition to the simulation results, the program also estimates the degree of certainty (or confidence, credibility). The degree of certainty provides the decision-maker with an additional piece of important information with which to evaluate the forecast results. NHTSA requests comment regarding the assumptions made and methods applied throughout this probabilistic uncertainty analysis.

Simulation Models and Uncertainty Factors

A Monte Carlo simulation was conducted using the CAFE modeling system that was developed to estimate the impacts of higher CAFE requirements described in previous chapters. The focus of the simulation model was variation around the chosen uncertainty parameters and their resulting impact on the key output parameters, fuel savings, and net benefits. Net benefits measure the difference between (1) the total dollar value that would be saved in fuel and other benefits and (2) the total costs of the rule.

The agency reviewed the inputs and relationships that drive the CAFE model to determine the factors that are the major sources of uncertainty. Six factors were identified as potentially contributing to uncertainty to the estimated impacts of higher CAFE standards, although not all were ultimately selected to be run in the simulation:

(1) Technology costs;
(2) Technology effectiveness;
(3) Fuel prices;
(4) The value of oil consumption externalities;
(5) Greenhouse gas emissions and;
(6) The rebound effect.

Technology Costs

The costs incurred by manufacturers to modify their vehicles to meet new CAFE levels are assumed to be passed on to consumers in the form of higher new car prices. These technology costs are the primary determinant of the overall cost of improving fuel economy.

Fifty-seven different technologies were examined as possible methods to comply with higher CAFE standards. These technologies were described in Chapter V earlier in this analysis. The expected cost values were used in the main analysis. For the uncertainty analysis, the agency modeled the plausible range of costs individually for each technology using beta distributions with mode values equal to the corresponding technology costs used in the central analysis. The beta distribution was chosen to represent the higher probability implicit in the central values, but also recognizing that alternative values recommended by the National Academy of Sciences (NAS) would also have some probability of occurring. For a variety of reasons discussed elsewhere in this analysis, the agency selected the central values different from the NAS recommendations. However, the purpose of an uncertainty analysis is to identify plausible alternate assumptions and reflect the possibility that these alternative values could occur. The agency calculated the ratio of total MY 2025 costs under the central values used in this analysis and compared them to the alternate values based on NAS recommendations and found that NAS recommended values were 1.45 times the central values[425]. The agency created a beta model based on a mode equal to the central value, with the tails defined based on the average confidence intervals found in the NAS study. This confidence interval (18.6%) was added to the NAS relative cost. There were no confidence intervals provided in the FEV reports[426], which defines the mode value, so the lower tail was defined as the absolute value of the difference between the NAS value and its upper confidence interval subtracted from the central values. This effectively assigned a confidence interval to the central values of 27%. Within these parameters, the agency chose alpha and beta values of 1.8 and 3.14, respectively, to assign a 5% probability that values chosen would be equal to or greater than the NAS costs. The use of beta distributions with the above parameters allow for a range of technology costs less than those used in the central analysis, in-between those of the central analysis and those of the NAS study, and above those of the NAS study, with the greatest weight assigned around the central NPRM values.

Technology Effectiveness

The modifications adopted by manufacturers to enable their vehicles to meet new CAFE levels will improve fuel efficiency and reduce the cost of operating the more efficient vehicles. The effectiveness of each technology determines how large an impact it will have towards enabling manufacturers to meet the higher CAFE standards, and will thus determine how much additional improvement is needed and which additional technologies will be required to achieve full compliance. In selecting the likely path that manufacturers will choose to meet CAFE, the CAFE model tests the interaction of technology costs and effectiveness to achieve an optimal (cost-minimizing) technological solution. Technology effectiveness is thus a primary determinant of the overall cost and benefit of improving fuel economy.

As noted above, fifty-seven different technologies were examined as possible methods to comply with higher CAFE standards. These technologies were described in Chapter V earlier in this analysis. Chapter V also summarizes the estimated range of effectiveness for these technologies. The expected values (mid-range values) were used in the main analysis. For the uncertainty analysis, the full range of effectiveness estimates is used except where the specified range was regarded as too narrow by expert opinion. These were adjusted to the ‘default’ range (29%). These technologies are:

Combustion Restart

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[425] This factor reflects differences in direct technology cost estimates, indirect cost markups, and rates of learning. It thus represents the full range of assumptions that influence cost estimates.

[426] It should be noted that, although the FEV cost study did not determine formal uncertainty ranges or confidence intervals, FEV did conduct sensitivity analysis for some of the technologies they estimated costs for, focusing on potential changes in labor and burden rates, material costs, and mark-ups such as engineering, profit, and end-item scrappage. This analysis found, for example, that a 20 percent decrease in labor rates would yield a 3 percent decrease in the cost of HEV technology.

Turbocharging and Downsizing
Exhaust Gas Recirculation (EGR) Boost
Conversion to Diesel following CBRST
Conversion to Diesel following TRBDS
Dual Clutch or Automated Manual Transmission
12V Micro-Hybrid
Belt mounted Integrated Starter Generator
Crank mounted Integrated Starter Generator
Plug-in Hybrid

The fuel consumption improvement ranges were regarded as either tight or were non-existent for these technologies because the values developed for them were not done with a mind toward what the average value should be (by vehicle class) and were not done with an eye towards uncertainty analysis.

As was done with costs, the average variation of all technologies where a range is specified was used as 3 standard deviations to be used as the default variation. For all technologies where there is no range specified, this default variation was used. The uncertainties model assumes a normal distribution for these values, with each end of the range being three standard deviations from the mean (or expected) value.

Fuel Prices

Higher CAFE standards will result in reduced gasoline consumption, which will translate into lower vehicle operating costs for consumers. The value of this reduced fuel consumption is a direct function of fuel prices. Fuel prices are thus a primary determinant of the overall social benefit that will result from improving fuel economy.

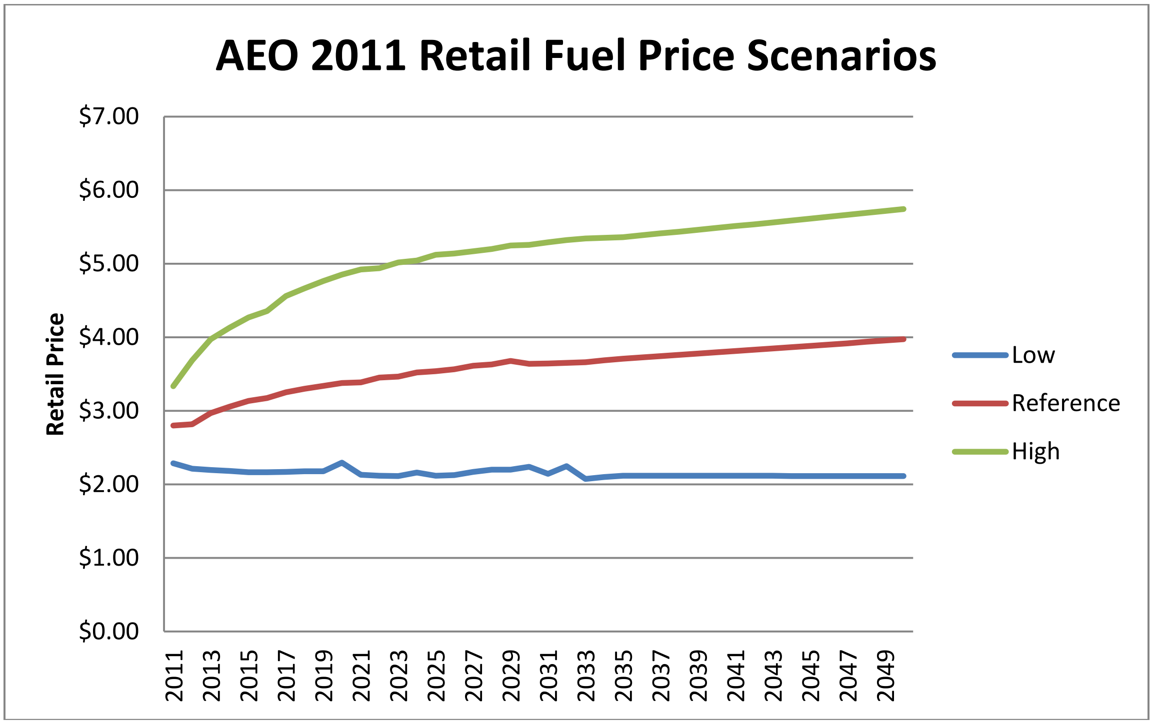
The analysis attempts to measure impacts that occur nearly 50 years in the future; estimating gasoline prices this far in advance is an uncertain process. In the main analysis, the agency utilized predicted fuel prices from the Energy Information Administration’s (EIA) publication Annual Energy Outlook 2011 Release (AEO). The main analysis is based on the AEO 2011 Reference Case scenario, which represents EIA’s current best estimate of future fuel prices. For the uncertainty analysis, the Agency examined two other AEO scenarios from the 2011 version, the Low Oil Price scenario (LOP) and the High Oil Price scenario (HOP). The LOP scenario was chosen to allow for the possibility that the EIA’s Reference Case predictions could overestimate the price of gasoline in the future. However, previous escalation in the price of gasoline resulted in prices that exceeded those estimated by EIA for their reference case. To reflect the possibility of significantly higher prices, the Agency selected the HOP case, which among the AEO 2011 scenarios comes closest to matching the highest prices seen during the recent gasoline price surge, and which gives the highest gasoline price forecasts among all AEO 2011 scenarios.

Each of these scenarios was applied as a discrete input (*i.e.*, draws were not made from among the three scenarios separately for each future year). Rather, for each draw, one of the three scenarios was chosen and applied across the full vehicle life for each model year. The probability of selection for each of the three scenarios was modeled using discrete weights of 50 percent for the Reference Case, and 25 percent for both the LOP and HOP cases. Table XII-1 lists the AEO gasoline price forecasts under each scenario. These same prices are demonstrated graphically (in 2009 economics) in Figure XII-1. Note that these prices include federal, state, and local fuel taxes. For the uncertainty analysis, taxes were removed because they are viewed as transfer payments (see discussion in Chapter VIII). Estimated retail prices are shown here because they are a better reference point for most readers.

Table XII-1
AEO 2011 Gasoline Price Scenarios

Year	Low	Reference	High
2011	$2.289	$2.802	$3.334
2012	$2.216	$2.818	$3.689
2013	$2.196	$2.971	$3.976
2014	$2.184	$3.055	$4.129
2015	$2.167	$3.134	$4.271
2016	$2.164	$3.176	$4.355
2017	$2.170	$3.252	$4.562
2018	$2.181	$3.300	$4.663
2019	$2.178	$3.340	$4.763
2020	$2.297	$3.378	$4.852
2021	$2.130	$3.388	$4.923
2022	$2.117	$3.453	$4.939
2023	$2.115	$3.467	$5.017
2024	$2.161	$3.520	$5.041
2025	$2.118	$3.539	$5.123
2026	$2.126	$3.564	$5.138
2027	$2.172	$3.615	$5.169
2028	$2.202	$3.630	$5.198
2029	$2.202	$3.677	$5.249
2030	$2.239	$3.640	$5.257
2031	$2.143	$3.643	$5.291
2032	$2.248	$3.653	$5.319
2033	$2.076	$3.662	$5.342
2034	$2.101	$3.689	$5.352
2035	$2.117	$3.707	$5.362
2036	$2.117	$3.724	$5.387
2037	$2.117	$3.742	$5.411
2038	$2.117	$3.759	$5.436
2039	$2.117	$3.776	$5.461
2040	$2.117	$3.794	$5.486
2041	$2.116	$3.812	$5.511
2042	$2.116	$3.829	$5.536
2043	$2.116	$3.847	$5.561
2044	$2.116	$3.865	$5.587
2045	$2.116	$3.883	$5.612
2046	$2.116	$3.901	$5.638
2047	$2.116	$3.919	$5.664
2048	$2.116	$3.937	$5.689
2049	$2.116	$3.956	$5.715
2050	$2.116	$3.974	$5.742

Figure XII-1



Oil Consumption Externalities

Reduced fuel consumption can benefit society by lowering the world market price for oil, reducing the threat of petroleum supply disruptions, and reducing the cost of maintaining military security in oil producing regions and operating the strategic petroleum reserve. These benefits are called "externalities" because they are not reflected directly in the market price of fuel. A full description of these externalities is included in Chapter VIII under "Other Economic Benefits from Reducing Petroleum Use." These factors increase the net social benefits from reduced fuel consumption. Although they represent a relatively small portion of overall social benefits, there is a significant level of uncertainty as to their values.[427]

Monopsony costs represent the reduced value of payments from U.S. oil purchasers to foreign oil suppliers that results when lower U.S. oil demand reduces the world price of petroleum, beyond the savings from reduced purchases of petroleum itself.[428] However, consistency with NHTSA's

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[427] For reasons noted in Chapter VIII, the agency opted not to conduct uncertainty analysis surrounding the military security externality. While there is uncertainty regarding the value of the military security externality, the agency believes that U.S. military expenditures are unlikely to be influenced significantly by this rule.

[428] The reduction in payments from U.S. oil purchasers to domestic petroleum producers is not included as a benefit, since it represents a transfer that occurs entirely within the U.S. economy.

use of estimates of the *global* benefits from reducing emissions of CO_2 and other greenhouse gases in this analysis requires the use of a global perspective for assessing their net value. From this perspective, reducing these payments simply results in a transfer of resources from foreign oil suppliers to U.S. purchasers (or more properly, in a savings in the value of resources previously transferred from U.S. purchasers to foreign producers), and provides no real savings in resources to the global economy. Thus NHTSA's analysis of the benefits from adopting higher CAFE standards for MY 2017-2025 cars and light trucks excludes the reduced value of monopsony payments by U.S. oil consumers that might result from lower fuel consumption by these vehicles, and they are likewise not included in the uncertainty analysis.

The second component of external economic costs imposed by U.S. petroleum imports arises partly because an increase in oil prices triggered by a disruption in the supply of imported oil reduces the level of output that the U.S. economy can produce. The reduction in potential U.S. economic output depends on the extent and duration of the increases in petroleum product prices that result from a disruption in the supply of imported oil, as well as on whether and how rapidly these prices return to pre-disruption levels. Even if prices for imported oil return completely to their original levels, however, economic output will be at least temporarily reduced from the level that would have been possible without a disruption in oil supplies. It is estimated that each gallon of fuel saved that results in a reduction in U.S. petroleum imports (either crude petroleum or refined fuel) will reduce the expected costs of oil supply disruptions to the U.S. economy by $0.081 to $0.278, with the actual value most likely to be $0.174 per gallon. The uncertainty analysis on this externality utilized a range of $0.05 to $0.29 per gallon, with a mean of $0.169 with a normal distribution and standard deviation of $0.05.

Greenhouse Gas Emissions

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 reducing the volume of fuel consumed by passenger cars and light trucks, higher CAFE standards will thus 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. In Chapter VIII, a more complete discussion of CO_2 emissions is presented along with a variety of estimates. The central estimate used in the analysis is $22 per metric ton. Additional scenarios are examined in Chapter X via sensitivity analyses at values of $5, $36, and $67 per metric ton. SCC was not included in this uncertainty analysis based on recommendations from the interagency working group that produced the SCC values employed in the agency's main analysis.

The Rebound Effect

By reducing the amount of gasoline used and, thus, the cost of operating a vehicle, higher CAFE standards are expected to result in a slight increase in annual miles driven per vehicle. This “rebound effect” impacts net societal benefits because the increase in miles driven offsets a portion of the gasoline savings that results from more fuel-efficient vehicles. Although consumers derive some value from this extra driving, it also leads to increases in crash, congestion, noise, and pollution costs associated with driving. Most recent estimates of the magnitude of the rebound effect for light duty vehicles fall in the range of 10-20 percent (*i.e.*, increasing vehicle use will offset 10-20 percent of the fuel savings resulting from an improvement in fuel economy), but studies also show that the rebound effect has been gradually decreasing over time. A more complete discussion of the rebound effect is included in Chapter VIII. The agency employed a rebound effect of 10 percent in the main analysis. For the uncertainty analysis, a range of 5 to 30 percent was used and employed in a slightly skewed Beta distribution which produced a mean of approximately 14.2 percent. The skewed distribution reflects the agency’s belief that the more credible studies that differ from the 10 percent value chosen for the main analysis fall below this value (*i.e.*, are more negative) and differ by more substantial margins than the upper range of credible values. Table XII-2 summarizes the economic parameters used in the uncertainty analysis.

Table XII-2
Monte Carlo Specific Parameters

Discount Rates (%)	0.03, 0.07
Fuel Path Randomization Parameters	
Low	25%
Reference	50%
High	25%
Rebound Effect Randomization Parameters	
Alpha Shape	1.50
Beta Shape	3.00
Scale	-0.25
Base	-0.05
Price Shock Randomization Parameters	
Mean	$0.169
Standard Deviation	$0.0547

Modeling Results – Trial Draws

Because of the complexity of the CAFE model, the computer time required to perform the uncertainty analysis was significant. The uncertainty analysis conducted a total of 50,000 trials (25,000 for each discount rate) Figures XII-2 through XII-11 graphically illustrate the draw results for a selected sample of the 117 variables (57 technology effectiveness rates, 57 technology costs, the fuel price scenario, oil import externalities, and the rebound effect) that were examined.

Although the full uncertainty ranges for all technologies are presented in Table XII-4 through XII-7, the agency chose to graphically highlight a subset of these technologies in Figure XII-2 through XII-7. These technologies were selected for illustrative purposes due to their high penetration rates and due to their importance as key enablers of the preferred alternative.

Figure XII-2
Monte Carlo Draw Profile, Passenger Car Costs

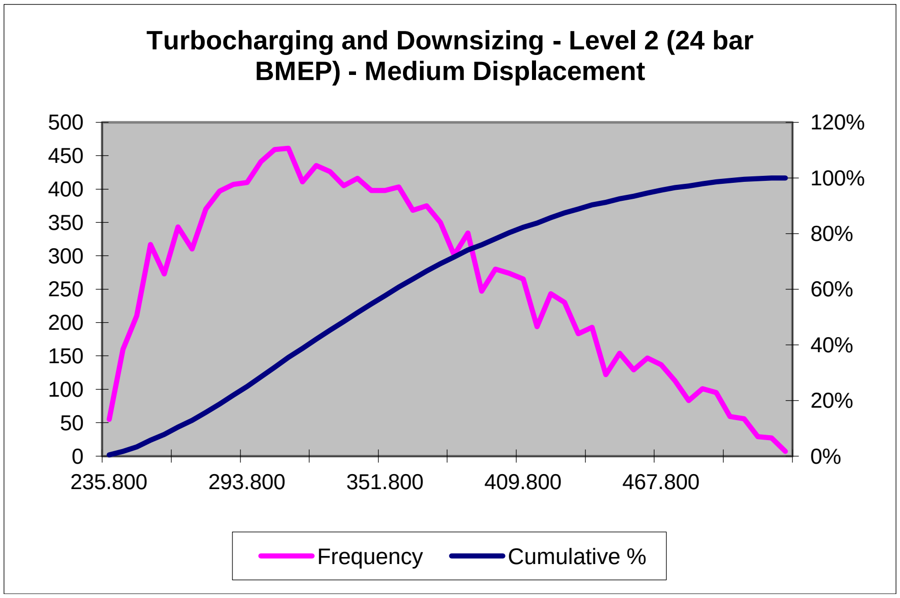

Figure XII-3
Monte Carlo Draw Profile, Passenger Car Effectiveness

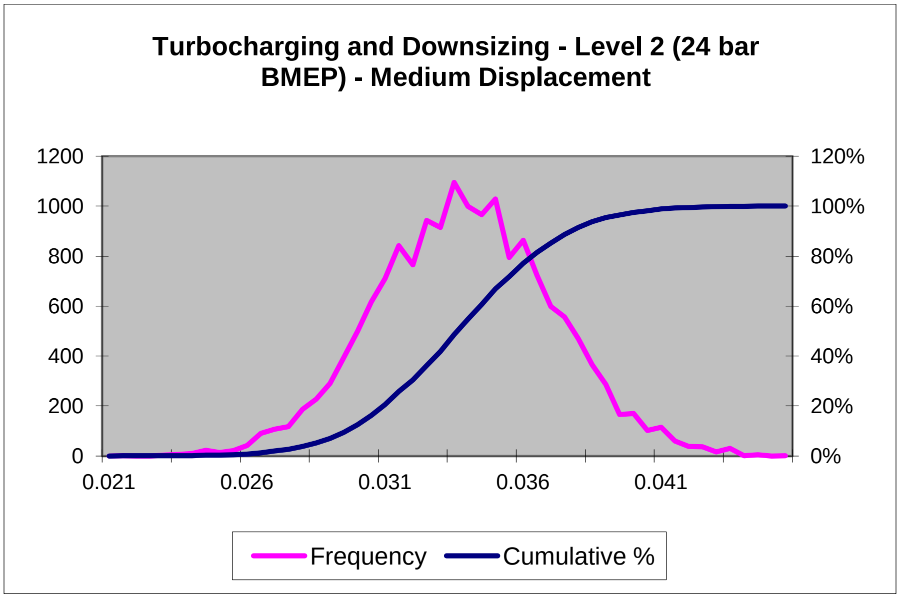

Figure XII-4
Monte Carlo Draw Profile, Passenger Cars, Costs

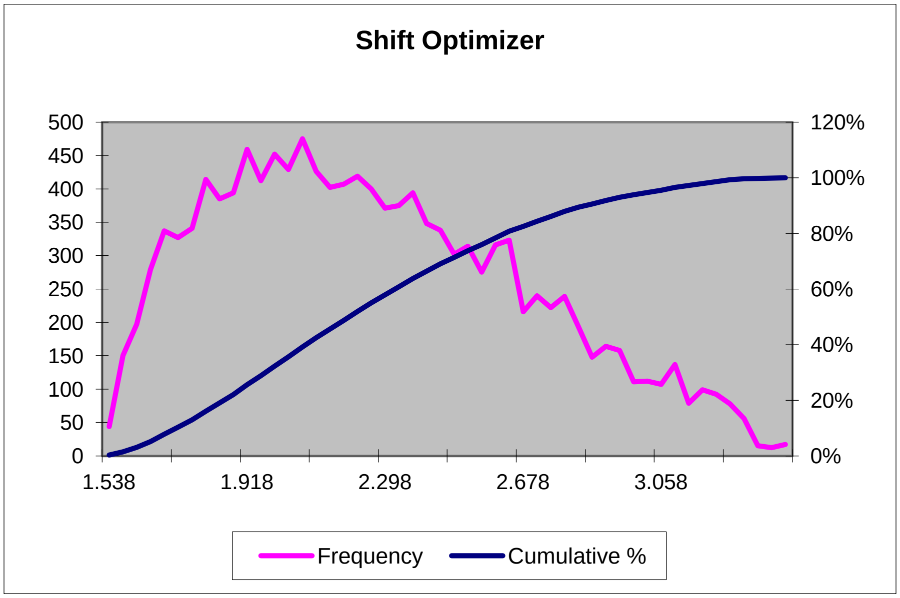

Figure XII-5
Monte Carlo Draw Profile, Passenger Cars, Effectiveness

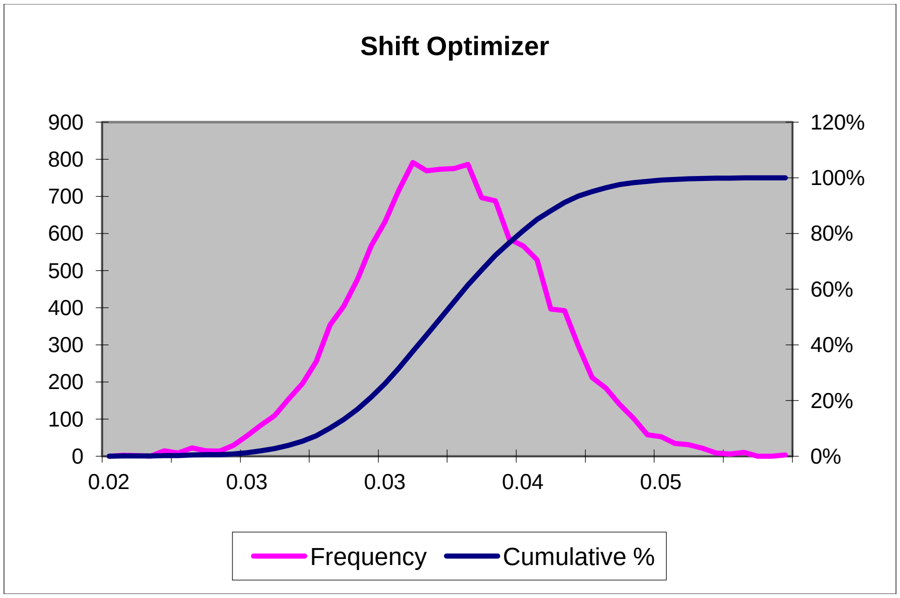

Figure XII-6
Monte Carlo Draw Profile, Passenger Cars, Costs

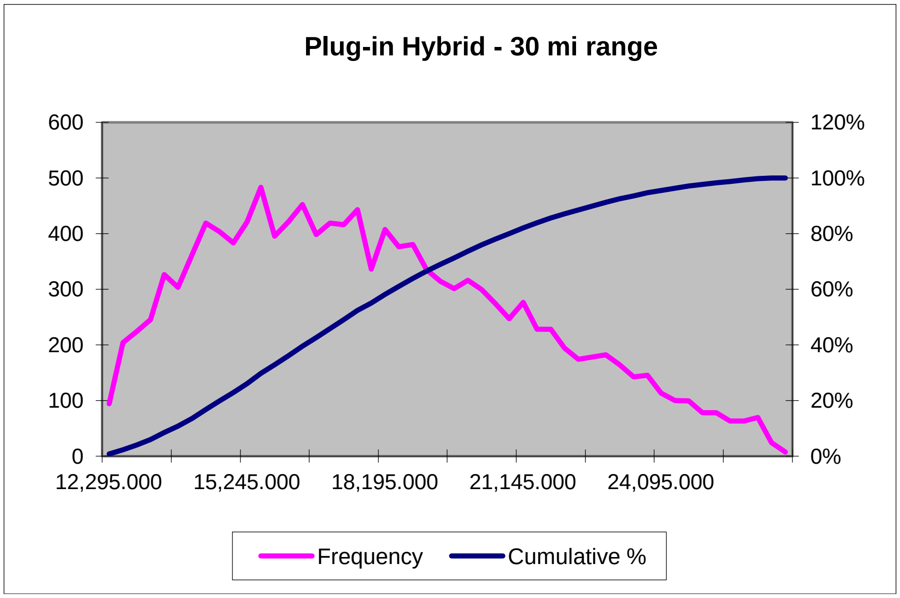

Figure XII-7
Monte Carlo Draw Profile, Passenger Cars, Effectiveness

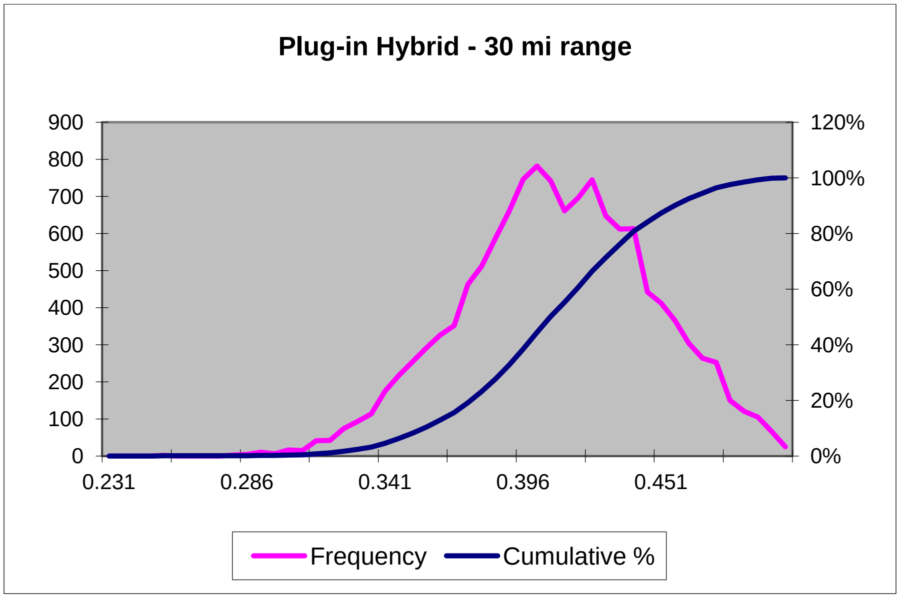

Figure XII-8
Monte Carlo Draw Profile
Pretax Fuel Price Path

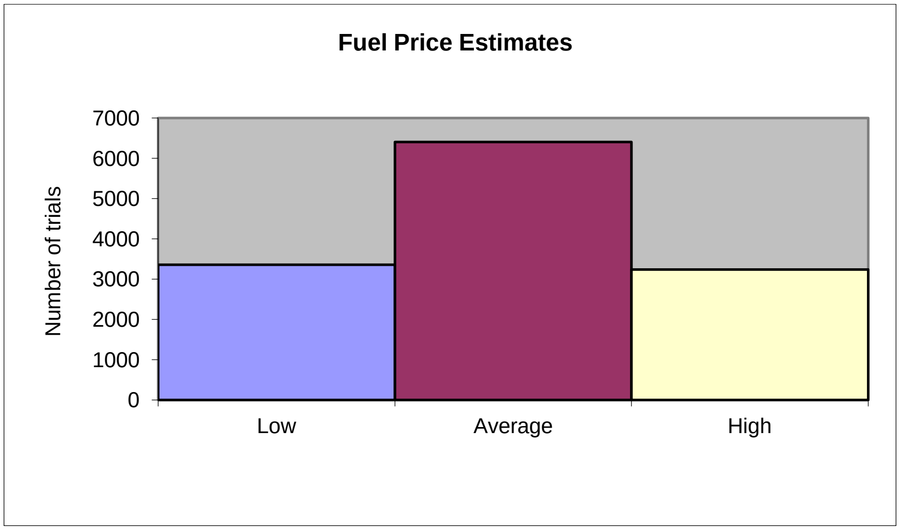

Figure XII-9
Monte Carlo Draw Profile

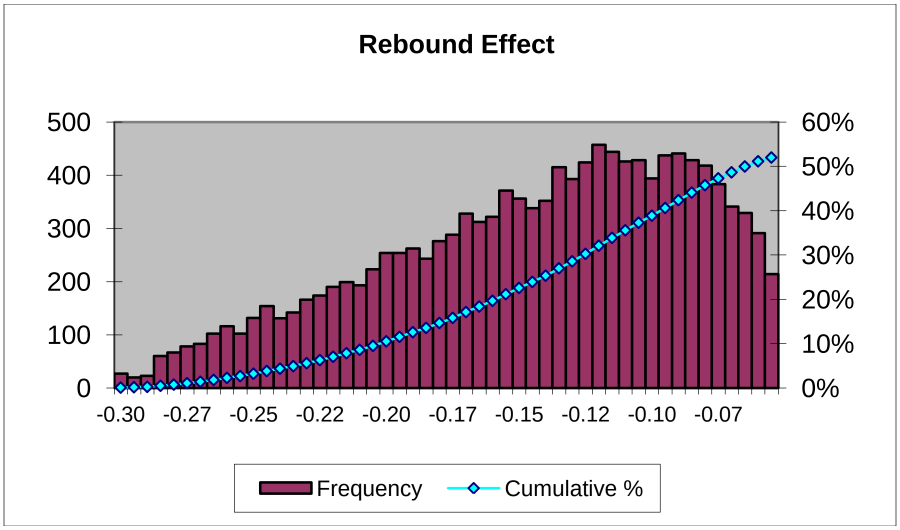

Figure XII-10
Monte Carlo Draw Profile

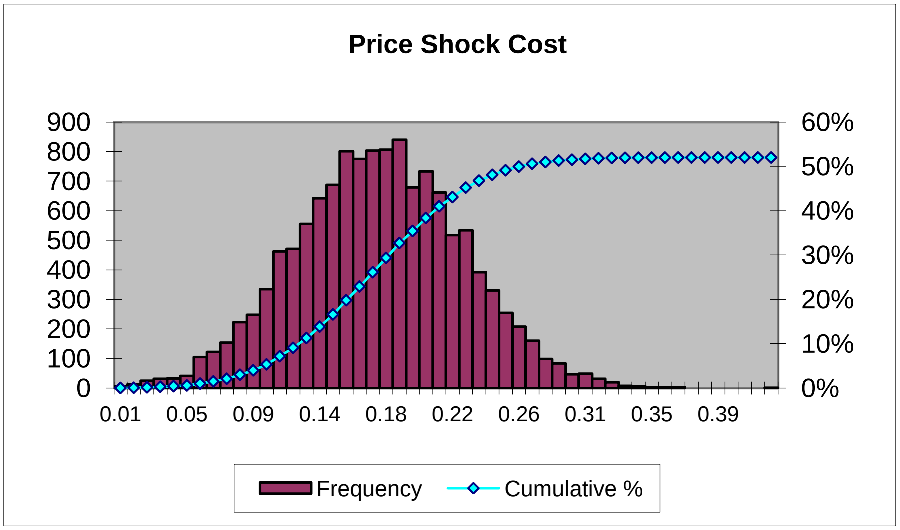

Table XII-3
Monte Carlo Draw Results, Economic Inputs

Economic Inputs	**Minimum**	**Maximum**	**Mean**	**StdDev**
Rebound Effect	-0.2993	-0.0500	-0.1422	0.0582
Price Shock Cost	0.0055	0.4218	0.1696	0.0535

Table XII-4

Monte Carlo Draw Results, Passenger Car Technology Costs

Technology	Minimum	Maximum	Mean	StDev
Low Friction Lubricants - Level 1	$2.97	$6.60	$4.38	$0.25
Engine Friction Reduction - Level 1	$11.25	$25.05	$16.63	$0.95
Low Friction Lubricants and Engine Friction Reduction - Level 2	$11.78	$26.24	$17.47	$0.99
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	$41.39	$92.23	$61.40	$3.49
Discrete Variable Valve Lift (DVVL) on SOHC	$35.89	$79.82	$53.31	$6.06
Cylinder Deactivation on SOHC	$28.75	$63.99	$42.65	$4.85
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	$41.37	$92.10	$61.30	$3.49
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	$39.00	$86.87	$57.62	$6.58
Discrete Variable Valve Lift (DVVL) on DOHC	$35.93	$80.02	$53.27	$6.06
Continuously Variable Valve Lift (CVVL)	$57.83	$128.82	$85.83	$9.76
Cylinder Deactivation on DOHC	$28.78	$64.03	$42.47	$4.85
Stoichiometric Gasoline Direct Injection (GDI)	$59.49	$131.85	$87.35	$10.03
Cylinder Deactivation on OHV	$182.88	$406.19	$271.40	$30.89
Variable Valve Actuation - CCP and DVVL on OHV	$45.84	$101.91	$67.60	$7.72
Stoichiometric Gasoline Direct Injection (GDI) on OHV	$59.36	$132.34	$87.74	$10.03
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	$428.87	$955.38	$636.18	$72.34
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	-$19.14	-$5.04	-$13.62	-$1.94
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	$550.21	$1,225.39	$816.91	$92.83
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	$8.83	$19.64	$13.09	$1.49
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	$232.16	$517.52	$344.68	$39.21
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	$391.02	$871.50	$579.50	$66.09
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement	$269.74	$600.96	$399.34	$45.59
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement	$270.08	$601.21	$401.36	$45.59
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement	$269.93	$602.43	$398.44	$45.59
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement	$464.27	$1,036.14	$688.68	$78.41
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement	$464.27	$1,034.08	$689.24	$78.41
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement	-$689.55	-$310.68	-$459.42	-$52.29

Advanced Diesel - Small Displacement	$837.43	$1,861.13	$1,236.89	$141.12
Advanced Diesel - Medium Displacement	$782.08	$1,732.77	$1,159.44	$131.80
Advanced Diesel - Large Displacement	$1,519.38	$3,372.23	$2,241.00	$255.95
6-Speed Manual/Improved Internals	$251.79	$559.26	$372.39	$21.23
High Efficiency Gearbox (Manual)	$228.11	$507.25	$338.93	$19.25
Improved Auto. Trans. Controls/Externals	$55.56	$123.89	$81.89	$4.69
6-Speed Trans with Improved Internals (Auto)	-$65.72	-$17.30	-$46.77	-$3.33
6-speed DCT	-$160.55	-$42.27	-$114.27	-$16.28
8-Speed Trans (Auto or DCT)	$220.54	$490.60	$326.46	$37.21
High Efficiency Gearbox (Auto or DCT)	$228.36	$508.36	$337.71	$19.25
Shift Optimizer	$1.52	$3.38	$2.25	$0.13
Electric Power Steering	$97.78	$217.85	$144.90	$8.25
Improved Accessories - Level 1	$79.52	$177.27	$118.18	$6.71
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	$48.78	$108.71	$72.33	$4.11
12V Micro-Hybrid (Stop-Start)	$394.87	$877.16	$584.75	$66.63
Strong Hybrid - Level 1	$3,463.26	$7,714.14	$5,140.26	$875.95
Conversion from SHEV1 to SHEV2	$1,104.46	$2,454.37	$1,638.16	$279.65
Strong Hybrid - Level 2	$3,465.87	$7,691.66	$5,120.43	$875.95
Plug-in Hybrid - 30 mi range	$12,001.82	$26,695.92	$17,806.60	$3,038.83
Mass Reduction - Level 1	$0.08	$0.18	$0.12	$0.01
Mass Reduction - Level 2	$0.37	$0.83	$0.55	$0.03
Mass Reduction - Level 3	$0.86	$1.92	$1.27	$0.07
Mass Reduction - Level 4	$1.36	$3.01	$2.01	$0.23
Mass Reduction - Level 5	$1.90	$4.22	$2.81	$0.32
Low Rolling Resistance Tires - Level 1	$4.94	$10.99	$7.32	$0.42
Low Rolling Resistance Tires - Level 2	$54.27	$120.71	$80.67	$4.58
Low Drag Brakes	$54.65	$120.98	$80.66	$4.59
Secondary Axle Disconnect	$87.21	$193.86	$129.09	$7.36
Aero Drag Reduction, Level 1	$43.68	$96.98	$64.48	$3.69
Aero Drag Reduction, Level 2	$144.82	$322.62	$214.24	$24.45

Table XII-5

Monte Carlo Draw Results, Passenger Car Fuel Economy Improvement Rates

Technology	Minimum	Maximum	Mean	StDev
Low Friction Lubricants - Level 1	0.003718	0.008507	0.006048	0.000583
Engine Friction Reduction - Level 1	0.013086	0.032408	0.022737	0.002562
Low Friction Lubricants and Engine Friction Reduction - Level 2	0.007109	0.015284	0.011253	0.001096
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	0.019440	0.073680	0.045551	0.007638
Discrete Variable Valve Lift (DVVL) on SOHC	0.014024	0.050632	0.031892	0.005302
Cylinder Deactivation on SOHC	0.004923	0.006100	0.005505	0.000167
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	0.014703	0.033821	0.023712	0.002570
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	0.016468	0.027945	0.022401	0.001501
Discrete Variable Valve Lift (DVVL) on DOHC	0.012326	0.051877	0.031909	0.005271
Continuously Variable Valve Lift (CVVL)	0.019104	0.060790	0.040413	0.005417
Cylinder Deactivation on DOHC	0.000046	0.011918	0.005526	0.001817
Stoichiometric Gasoline Direct Injection (GDI)	0.011277	0.019304	0.015366	0.001023
Cylinder Deactivation on OHV	0.040862	0.063508	0.052313	0.002935
Variable Valve Actuation - CCP and DVVL on OHV	0.018774	0.043881	0.030475	0.002923
Stoichiometric Gasoline Direct Injection (GDI) on OHV	0.011732	0.020169	0.015354	0.001030
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	0.049702	0.112120	0.077256	0.007435
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	0.045257	0.093517	0.070822	0.006633
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	0.046112	0.096710	0.070731	0.006760
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	0.021542	0.043703	0.031862	0.003099
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	0.020165	0.042812	0.031844	0.003076
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	0.020165	0.042851	0.031951	0.003113
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement	0.022159	0.047176	0.035933	0.003442
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement	0.023053	0.048356	0.035855	0.003476
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement	0.023053	0.048349	0.035856	0.003441
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement	0.007038	0.015818	0.011682	0.001140
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement	0.007756	0.015952	0.011662	0.001145
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement	0.007875	0.015898	0.011663	0.001137

Advanced Diesel - Small Displacement	0.028041	0.062888	0.043590	0.004209
Advanced Diesel - Medium Displacement	0.026210	0.062067	0.043515	0.004256
Advanced Diesel - Large Displacement	0.026221	0.058602	0.043553	0.004219
6-Speed Manual/Improved Internals	0.014301	0.029520	0.021842	0.002137
High Efficiency Gearbox (Manual)	0.023186	0.050453	0.037115	0.003552
Improved Auto. Trans. Controls/Externals	0.018384	0.034019	0.026144	0.002156
6-Speed Trans with Improved Internals (Auto)	0.008503	0.031733	0.019624	0.002747
6-speed DCT	0.025238	0.057992	0.039408	0.003786
8-Speed Trans (Auto or DCT)	0.027422	0.062362	0.042502	0.004193
High Efficiency Gearbox (Auto or DCT)	0.016072	0.034043	0.024396	0.002359
Shift Optimizer	0.023370	0.049545	0.036367	0.003567
Electric Power Steering	0.007395	0.019053	0.013547	0.001526
Improved Accessories - Level 1	0.006485	0.016358	0.011685	0.001302
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	0.012962	0.028109	0.020771	0.002046
12V Micro-Hybrid (Stop-Start)	0.012651	0.025608	0.018724	0.001800
Strong Hybrid - Level 1	0.081293	0.190755	0.131929	0.012815
Conversion from SHEV1 to SHEV2	0.074773	0.156006	0.113976	0.011162
Strong Hybrid - Level 2	0.051709	0.117326	0.085936	0.008357
Plug-in Hybrid - 30 mi range	0.249259	0.497496	0.406275	0.037756
Mass Reduction - Level 1	0.003800	0.008454	0.005760	0.000552
Mass Reduction - Level 2	0.016020	0.037734	0.025733	0.002550
Mass Reduction - Level 3	0.008618	0.018184	0.013268	0.001287
Mass Reduction - Level 4	0.016447	0.036764	0.026784	0.002627
Mass Reduction - Level 5	0.018896	0.036988	0.027642	0.002729
Low Rolling Resistance Tires - Level 1	0.010351	0.026261	0.018993	0.002151
Low Rolling Resistance Tires - Level 2	0.013798	0.027251	0.020372	0.001978
Low Drag Brakes	0.004790	0.010895	0.007996	0.000898
Secondary Axle Disconnect	0.009060	0.019529	0.013849	0.001339
Aero Drag Reduction, Level 1	0.017463	0.028139	0.022985	0.001524
Aero Drag Reduction, Level 2	0.014862	0.034597	0.024531	0.002373

Table XII-6

Monte Carlo Draw Results, Light Truck Technology Costs

Technology	Minimum	Maximum	Mean	StDev
Low Friction Lubricants - Level 1	$2.97	$6.60	$4.38	$0.25
Engine Friction Reduction - Level 1	$11.25	$25.05	$16.63	$0.95
Low Friction Lubricants and Engine Friction Reduction - Level 2	$11.78	$26.24	$17.46	$0.99
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	$41.39	$92.23	$61.39	$3.49
Discrete Variable Valve Lift (DVVL) on SOHC	$35.89	$79.82	$53.30	$6.06
Cylinder Deactivation on SOHC	$28.75	$63.99	$42.65	$4.85
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	$41.37	$92.10	$61.30	$3.49
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	$39.00	$86.87	$57.64	$6.58
Discrete Variable Valve Lift (DVVL) on DOHC	$35.93	$80.02	$53.25	$6.06
Continuously Variable Valve Lift (CVVL)	$57.83	$128.82	$85.83	$9.76
Cylinder Deactivation on DOHC	$28.78	$64.03	$42.51	$4.85
Stoichiometric Gasoline Direct Injection (GDI)	$59.49	$131.85	$87.39	$10.03
Cylinder Deactivation on OHV	$182.88	$406.19	$271.41	$30.89
Variable Valve Actuation - CCP and DVVL on OHV	$45.81	$101.91	$67.57	$7.72
Stoichiometric Gasoline Direct Injection (GDI) on OHV	$59.36	$132.34	$87.71	$10.03
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	$428.87	$955.38	$636.23	$72.34
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	-$19.14	-$5.04	-$13.63	-$1.94
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	$550.21	$1,225.39	$816.88	$92.83
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	$8.83	$19.64	$13.09	$1.49
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	$232.16	$517.52	$344.88	$39.21
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	$391.02	$871.50	$579.51	$66.09
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement	$269.74	$600.96	$399.45	$45.59
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement	$270.08	$601.21	$401.49	$45.59
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement	$269.93	$602.43	$398.43	$45.59
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement	$464.27	$1,036.14	$688.39	$78.41
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement	$464.27	$1,034.08	$689.24	$78.41
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement	-$689.55	-$310.68	-$459.61	-$52.29

Advanced Diesel - Small Displacement	$837.43	$1,861.13	$1,237.28	$141.12
Advanced Diesel - Medium Displacement	$782.08	$1,732.77	$1,158.74	$131.80
Advanced Diesel - Large Displacement	$1,519.38	$3,372.23	$2,240.29	$255.95
6-Speed Manual/Improved Internals	$251.79	$559.26	$372.31	$21.23
High Efficiency Gearbox (Manual)	$228.11	$507.25	$338.76	$19.25
Improved Auto. Trans. Controls/Externals	$55.56	$123.89	$81.92	$4.69
6-Speed Trans with Improved Internals (Auto)	-$65.72	-$17.30	-$46.78	-$3.33
6-speed DCT	-$133.53	-$35.15	-$95.06	-$13.54
8-Speed Trans (Auto or DCT)	$96.13	$213.85	$142.24	$16.22
High Efficiency Gearbox (Auto or DCT)	$228.36	$508.36	$337.75	$19.25
Shift Optimizer	$1.52	$3.38	$2.25	$0.13
Electric Power Steering	$97.78	$217.85	$144.95	$8.25
Improved Accessories - Level 1	$79.52	$177.27	$118.18	$6.71
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	$48.78	$108.71	$72.35	$4.11
12V Micro-Hybrid (Stop-Start)	$467.66	$1,038.85	$692.41	$78.91
Strong Hybrid - Level 1	$4,036.23	$8,990.39	$5,990.79	$1,020.86
Conversion from SHEV1 to SHEV2	$1,082.75	$2,406.11	$1,605.46	$274.15
Strong Hybrid - Level 2	$4,039.28	$8,964.20	$5,970.01	$1,020.86
Plug-in Hybrid - 30 mi range	$14,192.83	$31,569.44	$21,060.33	$3,593.59
Mass Reduction - Level 1	$0.07	$0.16	$0.11	$0.01
Mass Reduction - Level 2	$0.44	$0.99	$0.65	$0.04
Mass Reduction - Level 3	$0.86	$1.92	$1.27	$0.07
Mass Reduction - Level 4	$1.36	$3.01	$2.01	$0.23
Mass Reduction - Level 5	$1.90	$4.22	$2.81	$0.32
Low Rolling Resistance Tires - Level 1	$4.94	$10.99	$7.31	$0.42
Low Rolling Resistance Tires - Level 2	$54.27	$120.71	$80.67	$4.58
Low Drag Brakes	$54.65	$120.98	$80.61	$4.59
Secondary Axle Disconnect	$87.21	$193.86	$129.01	$7.36
Aero Drag Reduction, Level 1	$43.68	$96.98	$64.48	$3.69
Aero Drag Reduction, Level 2	$144.82	$322.62	$214.33	$24.45

Table XII-7

Monte Carlo Draw Results, Light Truck Fuel Economy Improvement Rates

Technology	Minimum	Maximum	Mean	StDev
Low Friction Lubricants - Level 1	0.004210	0.009634	0.006850	0.000662
Engine Friction Reduction - Level 1	0.014062	0.034826	0.024433	0.002752
Low Friction Lubricants and Engine Friction Reduction - Level 2	0.007305	0.015704	0.011561	0.001125
Variable Valve Timing (VVT) - Coupled Cam Phasing (CCP) on SOHC	0.020528	0.077804	0.048095	0.008054
Discrete Variable Valve Lift (DVVL) on SOHC	0.014836	0.053564	0.033735	0.005614
Cylinder Deactivation on SOHC	0.005443	0.006744	0.006086	0.000184
Variable Valve Timing (VVT) - Intake Cam Phasing (ICP)	0.015221	0.035012	0.024543	0.002659
Variable Valve Timing (VVT) - Dual Cam Phasing (DCP)	0.017773	0.030160	0.024180	0.001620
Discrete Variable Valve Lift (DVVL) on DOHC	0.013040	0.054881	0.033744	0.005582
Continuously Variable Valve Lift (CVVL)	0.020245	0.064422	0.042831	0.005750
Cylinder Deactivation on DOHC	0.000051	0.013176	0.006111	0.002006
Stoichiometric Gasoline Direct Injection (GDI)	0.011030	0.018882	0.015030	0.000999
Cylinder Deactivation on OHV	0.043525	0.067646	0.055725	0.003124
Variable Valve Actuation - CCP and DVVL on OHV	0.019716	0.046082	0.032003	0.003071
Stoichiometric Gasoline Direct Injection (GDI) on OHV	0.011476	0.019727	0.015016	0.001007
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Small Displacement	0.052977	0.119508	0.082338	0.007913
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Medium Displacement	0.048052	0.099294	0.075192	0.007046
Turbocharging and Downsizing - Level 1 (18 bar BMEP) - Large Displacement	0.048960	0.102684	0.075145	0.007183
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Small Displacement	0.022412	0.045469	0.033153	0.003224
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Medium Displacement	0.020980	0.044542	0.033136	0.003200
Turbocharging and Downsizing - Level 2 (24 bar BMEP) - Large Displacement	0.020980	0.044583	0.033232	0.003233
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Small Displacement	0.022154	0.047167	0.035933	0.003451
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Medium Displacement	0.023049	0.048347	0.035851	0.003472
Cooled Exhaust Gas Recirculation (EGR) - Level 1 (24 bar BMEP) - Large Displacement	0.023049	0.048341	0.035852	0.003441
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Small Displacement	0.006754	0.015178	0.011210	0.001094
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Medium Displacement	0.007442	0.015307	0.011187	0.001099
Cooled Exhaust Gas Recirculation (EGR) - Level 2 (27 bar BMEP) - Large Displacement	0.007556	0.015255	0.011189	0.001091

Advanced Diesel - Small Displacement	0.024187	0.054246	0.037605	0.003640
Advanced Diesel - Medium Displacement	0.022608	0.053537	0.037537	0.003665
Advanced Diesel - Large Displacement	0.022617	0.050549	0.037569	0.003634
6-Speed Manual/Improved Internals	0.015227	0.031431	0.023255	0.002274
High Efficiency Gearbox (Manual)	0.024814	0.053996	0.039716	0.003804
Improved Auto. Trans. Controls/Externals	0.019814	0.036665	0.028183	0.002324
6-Speed Trans with Improved Internals (Auto)	0.008911	0.033254	0.020565	0.002882
6-speed DCT	0.024358	0.055969	0.038036	0.003650
8-Speed Trans (Auto or DCT)	0.031879	0.072501	0.049422	0.004873
High Efficiency Gearbox (Auto or DCT)	0.021329	0.045179	0.032370	0.003127
Shift Optimizer	0.024828	0.052635	0.038630	0.003785
Electric Power Steering	0.005269	0.013575	0.009653	0.001088
Improved Accessories - Level 1	0.006421	0.016195	0.011569	0.001289
Improved Accessories - Level 2 (w/ Alternator Regen and 70% efficient alternator)	0.013627	0.029552	0.021834	0.002151
12V Micro-Hybrid (Stop-Start)	0.013748	0.027828	0.020346	0.001957
Strong Hybrid - Level 1	0.038480	0.090295	0.062460	0.006056
Conversion from SHEV1 to SHEV2	0.107501	0.224289	0.163842	0.016056
Strong Hybrid - Level 2	0.046878	0.106364	0.077896	0.007577
Plug-in Hybrid - 30 mi range	0.249259	0.555433	0.407479	0.039203
Mass Reduction - Level 1	0.003438	0.007699	0.005246	0.000503
Mass Reduction - Level 2	0.020653	0.048646	0.033182	0.003281
Mass Reduction - Level 3	0.008618	0.018184	0.013268	0.001285
Mass Reduction - Level 4	0.016447	0.036764	0.026790	0.002622
Mass Reduction - Level 5	0.018896	0.036988	0.027641	0.002730
Low Rolling Resistance Tires - Level 1	0.010351	0.026261	0.018991	0.002149
Low Rolling Resistance Tires - Level 2	0.013798	0.027251	0.020373	0.001977
Low Drag Brakes	0.004790	0.010895	0.007995	0.000897
Secondary Axle Disconnect	0.009240	0.019917	0.014129	0.001366
Aero Drag Reduction, Level 1	0.017463	0.028139	0.022983	0.001524
Aero Drag Reduction, Level 2	0.014862	0.034597	0.024534	0.002374

Modeling Results – Output

Tables XII-8, XII-9, and XII-10 summarize the modeling results for fuel saved, total costs, societal benefits, and net benefits for passenger cars and trucks respectively under a 7% discount rate. They also indicate the probability that net benefits exceed zero. Tables XII-11, XII-12, and XII-13 summarize these same results under a 3% discount rate. These results are also illustrated in Figures XII-11 through XII-14 for passenger cars under the Preferred Alternative at 7 percent for MY 2025. Although not shown here, the general shapes of the resulting output distributions are similar for the light trucks, for the 3 percent discount rate, and for other model years as well. The humped shape that occurs for both social benefits and net benefits reflects the three different gasoline price scenarios. About half of all draws were selected from the AEO Reference Case, while about one quarter were drawn from the Low Oil Price scenario and the remaining quarter were drawn from the High Oil Price scenario. This produces three separate humps which reflect the increasing impact on benefits from the three progressively higher oil price scenarios. The following discussions summarize the range of results presented in these tables for the combined passenger car and light truck fleets across both the 7 percent (typically the lower range) and 3 percent (typically upper range) discount rates.[429]

Fuel Savings: The analysis indicates that MY 2017 vehicles (both passenger cars and light trucks) will experience between 644,691 million and 4,542,934 million gallons of fuel savings over their useful lifespan. MY 2018 vehicles will experience between 1,537,303 million and 8,900,807 million gallons of fuel savings over their useful lifespan. MY 2019 vehicles will experience between 2,782,696 million and 14,432,098 million gallons of fuel savings over their useful lifespan. MY 2020 vehicles will experience between 4,117,149 million and 19,280,785 million gallons of fuel savings over their useful lifespan. MY 2021 vehicles will experience between 5,502,831 million and 24,490,035 million gallons of fuel savings over their useful lifespan. MY 2022 vehicles will experience between 6,498,640 million and 27,926,166 million gallons of fuel savings over their useful lifespan. MY 2023 vehicles will experience between 7,439,249 million and 31,195,803 million gallons of fuel savings over their useful lifespan. MY 2024 vehicles will experience between 9,079,553 million and 35,107,256 million gallons of fuel savings over their useful lifespan. MY 2025 vehicles will experience between 10,241,560 million and 38,772,920 million gallons of fuel savings over their useful lifespan.

Over the combined lifespan of the nine model years, between 47.8 trillion and 204.6 trillion gallons of fuel will be saved.

Total Costs: The analysis indicates that owners of MY 2017 passenger cars and light trucks will pay between $1,602 million and $5,523 million in higher vehicle prices to purchase vehicles with improved fuel efficiency. MY 2018 owners will pay between $3,855 million and $11,011 million more. MY 2019 owners will pay between $6,262 million and $16,953 million more. MY 2020 owners will pay between $9,234 million and $24,016 million more. MY 2021 owners will pay between $12,417 million and $33,314 million more. MY 2022 owners will pay between $14,696 million and $38,854 million more. MY 2023 owners will pay between $16,927 million

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[429] In a few cases the upper range results were obtained from the 7% rate and the lower range results were obtained from the 3% rate. While this may seem counterintuitive, it results from the random selection process that is inherent in the Monte Carlo technique.

and $46,742 million more. MY 2024 owners will pay between $20,791 million and $56,743 million more. MY 2025 owners will pay between $23,218 million and $60,415 million more.

Across all nine model years combined, owners will pay between $109.0 billion and $293.6 billion in higher vehicle prices to purchase vehicles with improved fuel efficiency.

Net of Societal Costs and Benefits: The analysis indicates that changes to passenger cars and light trucks to meet the proposed CAFE standards for each of the model years will produce overall net societal costs and benefits in the following ranges:

- MY 2017: Between -$288 million and $17,222 million
- MY 2018: Between $-497 million and $35,327 million
- MY 2019: Between $223 million and $58,946 million
- MY 2020: Between $1,808 million and $81,467 million
- MY 2021: Between $3,624 million and $104,546 million
- MY 2022: Between $5,899 million and $120,708 million
- MY 2023: Between $7,834 million and $135,694 million
- MY 2024: Between $11,843 million and $153,179 million
- MY 2025: Between $14,397 million and $169,968 million

Over the combined lifespan of the nine model years, societal benefits valued between $44.8 billion and $877.1 billion will be produced.

Net Benefits: The uncertainty analysis indicates that the net impact of the higher CAFE requirements for MY 2017 passenger cars and light trucks will be between a net cost of $3,485 million and a net benefit of $13,661 million. Assuming a 7 percent discount rate, there is a 93.7 percent certainty that changes made to the MY 2017 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 99.0 percent. Assuming a 3 percent discount rate, these values are 95.4 percent and 99.2 percent, respectively.

The net impact of the higher CAFE requirements for MY 2018 will be between a net cost of $6,956 million and a net benefit of $29,168 million. Assuming a 7 percent discount rate, there is a 95.6 percent certainty that changes made to the MY 2018 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 98.9 percent. Assuming a 3 percent discount rate, these values are 96.7 percent and 99.1 percent, respectively.

The net impact of the higher CAFE requirements for MY 2019 will be between a net cost of $9,578 million and a net benefit of $49,011 million. Assuming a 7 percent discount rate, there is a 96.4 percent certainty that changes made to the MY 2019 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 99.0 percent. Assuming a 3 percent discount rate, these values are 97.3 percent and 99.3 percent, respectively.

The net impact of the higher CAFE requirements for MY 2020 will be between a net cost of $13,308 million and a net benefit of $66,102 million. Assuming a 7 percent discount rate, there is a 94.7 percent certainty that changes made to the MY 2020 passenger car fleet to achieve the

CAFE standards will produce a net benefit. For light trucks, this value is 99.1 percent. Assuming a 3 percent discount rate, these values are 96.2 percent and 99.4 percent, respectively.

The net impact of the higher CAFE requirements for MY 2021 will be between a net cost of $17,197 million and a net benefit of $85,629 million. Assuming a 7 percent discount rate, there is a 94.4 percent certainty that changes made to the MY 2021 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 99.2 percent. Assuming a 3 percent discount rate, these values are 95.9 percent and 99.6 percent, respectively.

The net impact of the higher CAFE requirements for MY 2022 will be between a net cost of $18,437 million and a net benefit of $98,176 million. Assuming a 7 percent discount rate, there is a 92.8 percent certainty that changes made to the MY 2022 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 99.4 percent. Assuming a 3 percent discount rate, these values are 94.9 percent and 99.6 percent, respectively.

The net impact of the higher CAFE requirements for MY 2023 will be between a net cost of $21,683 million and a net benefit of $107,974 million. Assuming a 7 percent discount rate, there is a 92.2 percent certainty that changes made to the MY 2023 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 99.4 percent. Assuming a 3 percent discount rate, these values are 94.6 percent and 99.6 percent, respectively.

The net impact of the higher CAFE requirements for MY 2024 will be between a net cost of $25,240 million and a net benefit of $121,094 million. Assuming a 7 percent discount rate, there is a 87.7 percent certainty that changes made to the MY 2024 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 99.4 percent. Assuming a 3 percent discount rate, these values are 91.0 percent and 99.8 percent, respectively.

The net impact of the higher CAFE requirements for MY 2025 will be between a net cost of $24,675 million and a net benefit of $135,701 million. Assuming a 7 percent discount rate, there is an 89.1 percent certainty that changes made to the MY 2025 passenger car fleet to achieve the CAFE standards will produce a net benefit. For light trucks, this value is 99.6 percent. Assuming a 3 percent discount rate, these values are 92.4 percent and 99.7 percent, respectively.

Over all nine model years, the higher CAFE standards will produce a net impact ranging from a net cost of $140.6 billion to a net benefit of $706.5 billion. There is at least an 89.1 percent certainty that higher CAFE standards will produce a net societal benefit in each of the individual model years covered by this rule.

Table XII-8
UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS
(7% Discount Rate)

Item	Mean	Low	High
MY 2017			
Fuel Saved (mill. gall)	2,139,262	545,666	3,179,508
Total Cost ($mill.)	$2,534	$1,570	$4,263
Social Benefits ($mill.)	$4,858	-$149	$10,905
Net Benefits ($mill.)	$2,324	-$2,899	$7,847
% Certainty Net Ben. > 0	93.7%		
MY 2018			
Fuel Saved (mill. gall)	4,385,255	1,208,132	5,829,748
Total Cost ($mill.)	$5,059	$3,496	$7,383
Social Benefits ($mill.)	$10,011	-$224	$19,977
Net Benefits ($mill.)	$4,952	-$5,168	$14,902
% Certainty Net Ben. > 0	95.6%		
MY 2019			
Fuel Saved (mill. gall)	6,516,687	1,893,871	8,591,711
Total Cost ($mill.)	$7,363	$5,245	$10,403
Social Benefits ($mill.)	$15,075	$152	$29,643
Net Benefits ($mill.)	$7,712	-$6,905	$22,417
% Certainty Net Ben. > 0	96.4%		
MY 2020			
Fuel Saved (mill. gall)	8,765,015	2,586,146	11,381,740
Total Cost ($mill.)	$10,418	$7,663	$13,731
Social Benefits ($mill.)	$20,473	$523	$40,206
Net Benefits ($mill.)	$10,055	-$9,492	$29,844
% Certainty Net Ben. > 0	94.7%		
MY 2021			
Fuel Saved (mill. gall)	10,683,930	3,343,739	13,752,762
Total Cost ($mill.)	$13,499	$9,873	$19,122
Social Benefits ($mill.)	$25,204	$1,497	$49,717
Net Benefits ($mill.)	$11,704	-$11,581	$35,705
% Certainty Net Ben. > 0	94.4%		
Item	Mean	Low	High
MY 2022			
Fuel Saved (mill. gall)	12,295,079	3,993,975	15,829,617
Total Cost ($mill.)	$16,344	$11,858	$22,942
Social Benefits ($mill.)	$29,303	$3,207	$57,930
Net Benefits ($mill.)	$12,959	-$12,827	$40,153
% Certainty Net Ben. > 0	92.8		
MY 2023			

Fuel Saved (mill. gall)	13,867,981	4,592,028	17,714,203
Total Cost ($mill.)	$19,512	$13,960	$26,333
Social Benefits ($mill.)	$33,352	$4,357	$65,269
Net Benefits ($mill.)	$13,840	-$15,055	$44,940
% Certainty Net Ben. > 0	92.2%		
MY 2024			
Fuel Saved (mill. gall)	16,242,324	5,712,768	20,550,290
Total Cost ($mill.)	$25,156	$18,410	$37,298
Social Benefits ($mill.)	$39,586	$7,287	$75,840
Net Benefits ($mill.)	$14,429	-$19,205	$51,259
% Certainty Net Ben. > 0	87.7%		
MY 2025			
Fuel Saved (mill. gall)	18,130,642	6,435,596	22,693,413
Total Cost ($mill.)	$27,240	$20,942	$37,767
Social Benefits ($mill.)	$44,404	$8,625	$84,280
Net Benefits ($mill.)	$17,164	-$19,423	$58,876
% Certainty Net Ben. > 0	89.1%		

Table XII-9
UNCERTAINTY ANALYSIS RESULTS, LIGHT TRUCKS
(7% Discount Rate)

Item	Mean	Low	High
MY 2017			
Fuel Saved (mill. gall)	552,299	99,025	1,363,426
Total Cost ($mill.)	$363	$33	$764
Social Benefits ($mill.)	$1,243	$46	$3,751
Net Benefits ($mill.)	$880	-$342	$3,189
% Certainty Net Ben. > 0	99.0%		
MY 2018			
Fuel Saved (mill. gall)	1,958,175	329,171	3,071,060
Total Cost ($mill.)	$1,158	$808	$1,678
Social Benefits ($mill.)	$4,442	-$32	$9,942
Net Benefits ($mill.)	$3,284	-$1,065	$8,594
% Certainty Net Ben. > 0	98.9%		
MY 2019			
Fuel Saved (mill. gall)	4,169,501	969,634	5,840,379
Total Cost ($mill.)	$2,623	$1,793	$4,205
Social Benefits ($mill.)	$9,480	$328	$18,859
Net Benefits ($mill.)	$6,857	-$2,231	$16,099
% Certainty Net Ben. > 0	99.0%		
MY 2020			
Fuel Saved (mill. gall)	5,856,561	1,531,003	7,895,966
Total Cost ($mill.)	$4,224	$2,728	$6,361
Social Benefits ($mill.)	$13,506	$1,285	$26,114
Net Benefits ($mill.)	$9,282	-$3,478	$22,008
% Certainty Net Ben. > 0	99.2%		
MY 2021			
Fuel Saved (mill. gall)	8,132,800	2,159,092	10,577,787
Total Cost ($mill.)	$6,106	$4,145	$8,993
Social Benefits ($mill.)	$18,967	$2,127	$36,623
Net Benefits ($mill.)	$12,861	-$4,451	$30,577
% Certainty Net Ben. > 0	99.2%		
Item	Mean	Low	High
MY 2022			
Fuel Saved (mill. gall)	9,198,573	2,504,665	11,901,346
Total Cost ($mill.)	$6,893	$4,710	$9,908
Social Benefits ($mill.)	$21,699	$2,691	$41,593
Net Benefits ($mill.)	$14,806	-$4,619	$35,128
% Certainty Net Ben. > 0	99.4%		
MY 2023			

Fuel Saved (mill. gall)	10,198,763	2,847,221	13,283,878
Total Cost ($mill.)	$7,949	$5,401	$10,967
Social Benefits ($mill.)	$24,347	$3,477	$46,469
Net Benefits ($mill.)	$16,397	-$5,007	$39,434
% Certainty Net Ben. > 0	99.4%		
MY 2024			
Fuel Saved (mill. gall)	11,205,318	3,363,785	14,385,058
Total Cost ($mill.)	$8,940	$6,195	$12,522
Social Benefits ($mill.)	$27,013	$4,556	$51,281
Net Benefits ($mill.)	$18,073	-$5,187	$43,476
% Certainty Net Ben. > 0	99.4%		
MY 2025			
Fuel Saved (mill. gall)	12,326,933	3,805,964	15,647,996
Total Cost ($mill.)	$9,895	$6,973	$13,348
Social Benefits ($mill.)	$29,884	$5,771	$56,832
Net Benefits ($mill.)	$19,989	-$5,026	$48,372
% Certainty Net Ben. > 0	99.6%		

Table XII-10[430]
UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS AND LIGHT TRUCKS
(7% Discount Rate)

Item	Mean	Low	High
MY 2017			
Fuel Saved (mill. gall)	2,691,561	644,691	4,542,934
Total Cost ($mill.)	$2,897	$1,602	$5,026
Social Benefits ($mill.)	$6,102	-$103	$14,657
Net Benefits ($mill.)	$3,205	-$3,241	$11,036
% Certainty Net Ben. > 0	95.4%		
MY 2018			
Fuel Saved (mill. gall)	6,343,430	1,537,303	8,900,807
Total Cost ($mill.)	$6,216	$4,304	$9,061
Social Benefits ($mill.)	$14,453	-$255	$29,919
Net Benefits ($mill.)	$8,236	-$6,233	$23,495
% Certainty Net Ben. > 0	96.7%		
MY 2019			
Fuel Saved (mill. gall)	10,686,188	2,863,505	14,432,090
Total Cost ($mill.)	$9,986	$7,038	$14,608
Social Benefits ($mill.)	$24,555	$480	$48,502
Net Benefits ($mill.)	$14,569	-$9,136	$38,517
% Certainty Net Ben. > 0	97.3%		
MY 2020			
Fuel Saved (mill. gall)	14,621,576	4,117,149	19,277,706
Total Cost ($mill.)	$14,642	$10,390	$20,093
Social Benefits ($mill.)	$33,980	$1,808	$66,320
Net Benefits ($mill.)	$19,337	-$12,970	$51,852
% Certainty Net Ben. > 0	96.2%		
MY 2021			
Fuel Saved (mill. gall)	18,816,730	5,502,831	24,330,549
Total Cost ($mill.)	$19,606	$14,018	$28,115
Social Benefits ($mill.)	$44,171	$3,624	$86,340
Net Benefits ($mill.)	$24,565	-$16,031	$66,282
% Certainty Net Ben. > 0	95.9%		
Item	Mean	Low	High
MY 2022			
Fuel Saved (mill. gall)	21,493,652	6,498,640	27,730,963
Total Cost ($mill.)	$23,237	$16,568	$32,850
Social Benefits ($mill.)	$51,003	$5,899	$99,524

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[430] In Table XII-10, values presented in rows labeled "% Certainty Net Ben. > 0" were selected as the minimum of the corresponding rows in Table XII-8 and XII-9.

Net Benefits ($mill.)	$27,765	-$17,446	$75,282
% Certainty Net Ben. > 0	94.9%		
MY 2023			
Fuel Saved (mill. gall)	24,066,744	7,439,249	30,998,081
Total Cost ($mill.)	$27,462	$19,361	$37,299
Social Benefits ($mill.)	$57,699	$7,834	$111,738
Net Benefits ($mill.)	$30,237	-$20,062	$84,374
% Certainty Net Ben. > 0	94.6%		
MY 2024			
Fuel Saved (mill. gall)	27,447,641	9,076,553	34,935,348
Total Cost ($mill.)	$34,095	$24,605	$49,820
Social Benefits ($mill.)	$66,599	$11,843	$127,121
Net Benefits ($mill.)	$32,503	-$24,392	$94,735
% Certainty Net Ben. > 0	91.0%		
MY 2025			
Fuel Saved (mill. gall)	30,457,574	10,241,560	38,341,409
Total Cost ($mill.)	$37,135	$27,915	$51,115
Social Benefits ($mill.)	$74,288	$14,397	$141,111
Net Benefits ($mill.)	$37,153	-$24,448	$107,248
% Certainty Net Ben. > 0	92.4%		

Combining MY 2017-2025

Total Benefits at 7% discount rate: Societal benefits will total $46 billion to $725 billion, with a mean estimate of $373 billion.

Total Costs at 7% discount rate: Costs will total between $125 billion and $247 billion, with a mean estimate of $175 billion.

Table XII-11
UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS
(3% Discount Rate)

Item	Mean	Low	High
MY 2017			
Fuel Saved (mill. gall)	2,143,528	544,696	3,152,288
Total Cost ($mill.)	$2,537	$1,468	$4,698
Social Benefits ($mill.)	$5,887	-$317	$12,132
Net Benefits ($mill.)	$3,349	-$3,128	$9,269
% Certainty Net Ben. > 0	97.0%		
MY 2018			
Fuel Saved (mill. gall)	4,398,689	1,154,578	5,900,055
Total Cost ($mill.)	$5,060	$3,057	$9,098
Social Benefits ($mill.)	$12,125	-$426	$23,839
Net Benefits ($mill.)	$7,064	-$5,712	$18,859
% Certainty Net Ben. > 0	97.4%		
MY 2019			
Fuel Saved (mill. gall)	6,531,989	1,821,653	8,544,555
Total Cost ($mill.)	$7,360	$4,523	$12,210
Social Benefits ($mill.)	$18,225	-$82	$35,780
Net Benefits ($mill.)	$10,864	-$7,328	$28,792
% Certainty Net Ben. > 0	97.7%		
MY 2020			
Fuel Saved (mill. gall)	8,780,448	2,566,760	11,485,217
Total Cost ($mill.)	$10,411	$6,625	$16,415
Social Benefits ($mill.)	$24,724	$506	$49,058
Net Benefits ($mill.)	$14,311	-$9,839	$38,151
% Certainty Net Ben. > 0	97.7%		
MY 2021			
Fuel Saved (mill. gall)	10,702,138	3,361,993	13,830,051
Total Cost ($mill.)	$13,458	$8,631	$22,056
Social Benefits ($mill.)	$30,407	$1,740	$59,930
Net Benefits ($mill.)	$16,947	-$13,052	$46,377
% Certainty Net Ben. > 0	97.4%		
Item	Mean	Low	High
MY 2022			
Fuel Saved (mill. gall)	12,310,136	3,980,500	15,843,829
Total Cost ($mill.)	$16,248	$10,270	$26,528
Social Benefits ($mill.)	$35,302	$3,731	$69,588
Net Benefits ($mill.)	$19,051	-$14,236	$52,903
% Certainty Net Ben. > 0	97.7%		
MY 2023			

Fuel Saved (mill. gall)	13,903,406	4,627,909	17,731,811
Total Cost ($mill.)	$19,467	$11,786	$32,984
Social Benefits ($mill.)	$40,219	$5,140	$78,777
Net Benefits ($mill.)	$20,750	-$17,314	$57,870
% Certainty Net Ben. > 0	97.4%		
MY 2024			
Fuel Saved (mill. gall)	16,293,533	5,822,643	20,624,317
Total Cost ($mill.)	$25,167	$14,987	$41,334
Social Benefits ($mill.)	$47,698	$8,723	$90,211
Net Benefits ($mill.)	$22,529	-$20,876	$66,461
% Certainty Net Ben. > 0	95.1%		
MY 2025			
Fuel Saved (mill. gall)	18,209,943	6,547,000	23,036,427
Total Cost ($mill.)	$27,304	$16,817	$43,924
Social Benefits ($mill.)	$53,512	$9,921	$100,929
Net Benefits ($mill.)	$26,205	-$20,604	$75,158
% Certainty Net Ben. > 0	97.3%		

Table XII-12
UNCERTAINTY ANALYSIS RESULTS, LIGHT TRUCKS
(3% Discount Rate)

Item	Mean	Low	High
MY 2017			
Fuel Saved (mill. gall)	571,986	101,701	1,245,768
Total Cost ($mill.)	$381	$156	$826
Social Benefits ($mill.)	$1,587	$29	$5,090
Net Benefits ($mill.)	$1,205	-$357	$4,392
% Certainty Net Ben. > 0	99.2%		
MY 2018			
Fuel Saved (mill. gall)	1,979,929	418,428	2,969,104
Total Cost ($mill.)	$1,186	$798	$1,913
Social Benefits ($mill.)	$5,511	-$71	$11,488
Net Benefits ($mill.)	$4,325	-$1,245	$10,308
% Certainty Net Ben. > 0	99.1%		
MY 2019			
Fuel Saved (mill. gall)	4,189,512	961,043	5,813,968
Total Cost ($mill.)	$2,654	$1,739	$4,743
Social Benefits ($mill.)	$11,702	$305	$23,167
Net Benefits ($mill.)	$9,047	-$2,251	$20,220
% Certainty Net Ben. > 0	99.3%		
MY 2020			
Fuel Saved (mill. gall)	5,873,525	1,606,941	7,795,568
Total Cost ($mill.)	$4,246	$2,609	$7,601
Social Benefits ($mill.)	$16,569	$1,470	$32,409
Net Benefits ($mill.)	$12,322	-$3,468	$27,951
% Certainty Net Ben. > 0	99.4%		
MY 2021			
Fuel Saved (mill. gall)	8,164,790	2,253,878	10,659,984
Total Cost ($mill.)	$6,101	$3,786	$11,258
Social Benefits ($mill.)	$23,309	$2,581	$44,616
Net Benefits ($mill.)	$17,208	-$4,145	$39,252
% Certainty Net Ben. > 0	99.6%		
Item	Mean	Low	High
MY 2022			
Fuel Saved (mill. gall)	9,260,134	2,573,210	12,082,337
Total Cost ($mill.)	$6,912	$4,427	$12,326
Social Benefits ($mill.)	$26,699	$3,125	$51,120
Net Benefits ($mill.)	$19,787	-$4,201	$45,273
% Certainty Net Ben. > 0	99.6%		
MY 2023			

Fuel Saved (mill. gall)	10,280,841	2,966,338	13,463,992
Total Cost ($mill.)	$7,990	$5,141	$13,757
Social Benefits ($mill.)	$29,976	$4,108	$56,917
Net Benefits ($mill.)	$21,986	-$4,369	$50,104
% Certainty Net Ben. > 0	99.6%		
MY 2024			
Fuel Saved (mill. gall)	11,281,602	3,494,768	14,482,939
Total Cost ($mill.)	$8,971	$5,804	$15,409
Social Benefits ($mill.)	$33,193	$5,470	$62,968
Net Benefits ($mill.)	$24,221	-$4,364	$54,632
% Certainty Net Ben. > 0	99.8%		
MY 2025			
Fuel Saved (mill. gall)	12,385,163	3,893,886	15,736,493
Total Cost ($mill.)	$9,899	$6,401	$16,491
Social Benefits ($mill.)	$36,616	$6,975	$69,038
Net Benefits ($mill.)	$26,717	-$4,071	$60,543
% Certainty Net Ben. > 0	99.7%		

Table XII-13[431]

UNCERTAINTY ANALYSIS RESULTS, PASSENGER CARS AND LIGHT TRUCKS

(3% Discount Rate)

Item	Mean	Low	High
MY 2017			
Fuel Saved (mill. gall)	2,715,514	646,396	4,398,055
Total Cost ($mill.)	$2,918	$1,625	$5,523
Social Benefits ($mill.)	$7,473	-$288	$17,222
Net Benefits ($mill.)	$4,555	-$3,485	$13,661
% Certainty Net Ben. > 0	93.7%		
MY 2018			
Fuel Saved (mill. gall)	6,378,619	1,573,006	8,869,159
Total Cost ($mill.)	$6,246	$3,855	$11,011
Social Benefits ($mill.)	$17,636	-$497	$35,327
Net Benefits ($mill.)	$11,389	-$6,956	$29,168
% Certainty Net Ben. > 0	95.6%		
MY 2019			
Fuel Saved (mill. gall)	10,721,501	2,782,696	14,358,523
Total Cost ($mill.)	$10,014	$6,262	$16,953
Social Benefits ($mill.)	$29,927	$223	$58,946
Net Benefits ($mill.)	$19,912	-$9,578	$49,011
% Certainty Net Ben. > 0	96.4%		
MY 2020			
Fuel Saved (mill. gall)	14,653,973	4,173,701	19,280,785
Total Cost ($mill.)	$14,657	$9,234	$24,016
Social Benefits ($mill.)	$41,292	$1,975	$81,467
Net Benefits ($mill.)	$26,634	-$13,308	$66,102
% Certainty Net Ben. > 0	94.7%		
MY 2021			
Fuel Saved (mill. gall)	18,866,928	5,615,872	24,490,035
Total Cost ($mill.)	$19,559	$12,417	$33,314
Social Benefits ($mill.)	$53,716	$4,321	$104,546
Net Benefits ($mill.)	$34,155	-$17,197	$85,629
% Certainty Net Ben. > 0	94.4%		
Item	Mean	Low	High
MY 2022			
Fuel Saved (mill. gall)	21,570,270	6,553,710	27,926,166
Total Cost ($mill.)	$23,161	$14,696	$38,854
Social Benefits ($mill.)	$62,000	$6,857	$120,708

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[431] In Table XII-13, values presented in rows labeled "% Certainty Net Ben. > 0" were selected as the minimum of the corresponding rows in Table XII-11 and XII-12.

Net Benefits ($mill.)	$38,838	-$18,437	$98,176
% Certainty Net Ben. > 0	92.8%		
MY 2023			
Fuel Saved (mill. gall)	24,184,247	7,594,247	31,195,803
Total Cost ($mill.)	$27,458	$16,927	$46,742
Social Benefits ($mill.)	$70,196	$9,248	$135,694
Net Benefits ($mill.)	$42,736	-$21,683	$107,974
% Certainty Net Ben. > 0	92.2%		
MY 2024			
Fuel Saved (mill. gall)	27,575,135	9,317,410	35,107,256
Total Cost ($mill.)	$34,138	$20,791	$56,743
Social Benefits ($mill.)	$80,891	$14,192	$153,179
Net Benefits ($mill.)	$46,750	-$25,240	$121,094
% Certainty Net Ben. > 0	87.7%		
MY 2025			
Fuel Saved (mill. gall)	30,595,106	10,440,886	38,772,920
Total Cost ($mill.)	$37,202	$23,218	$60,415
Social Benefits ($mill.)	$90,128	$16,896	$169,968
Net Benefits ($mill.)	$52,923	-$24,675	$135,701
% Certainty Net Ben. > 0	89.1%		

Combining MY 2017-2025

Total Benefits at 3% discount rate: Societal benefits will total $53 billion to $877 billion, with a mean estimate of $453 billion.

Total Costs at 3% discount rate: Costs will total between $109 billion and $294 billion, with a mean estimate of $175 billion.

FIGURE XII-11
Model Output Profile

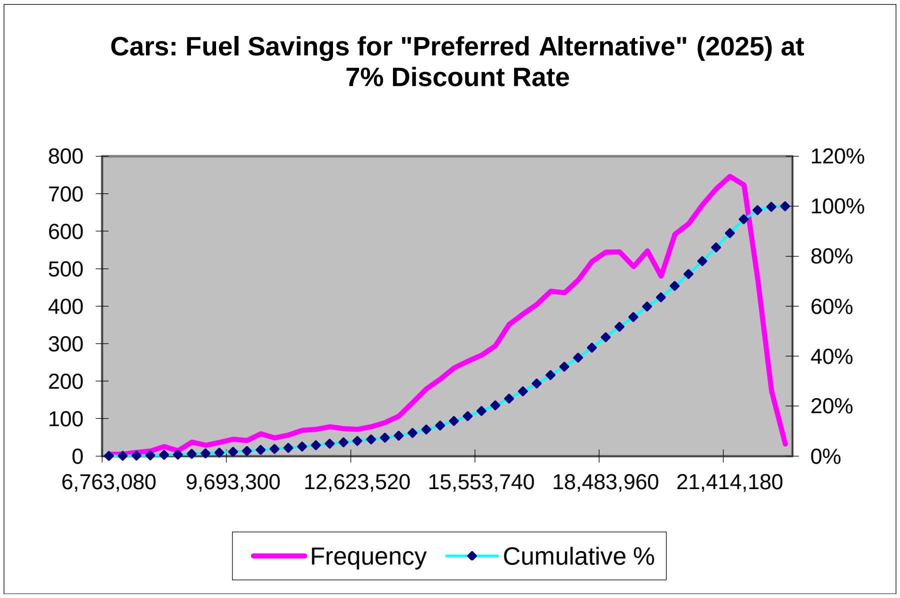


FIGURE XII-12
Model Output Profile

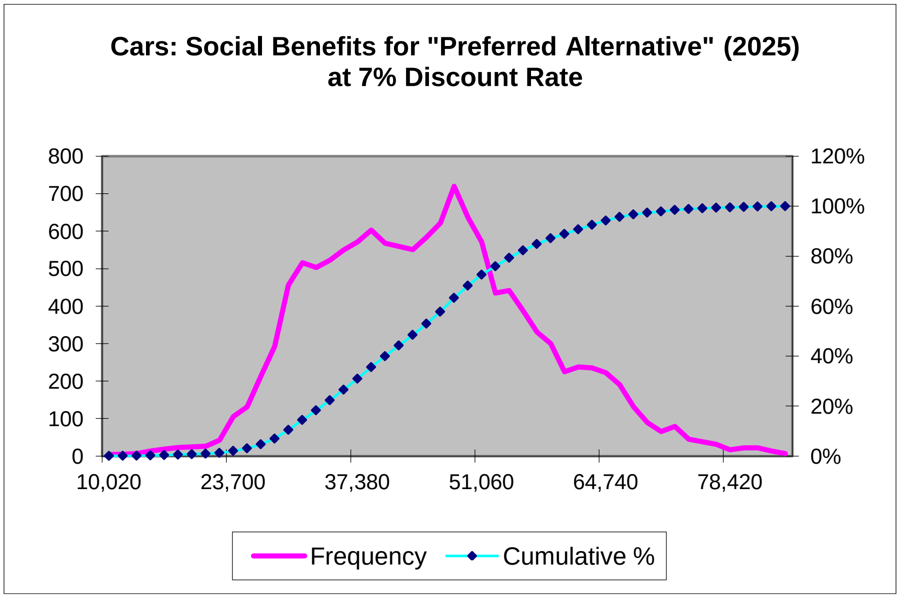


FIGURE XII-13
Model Output Profile

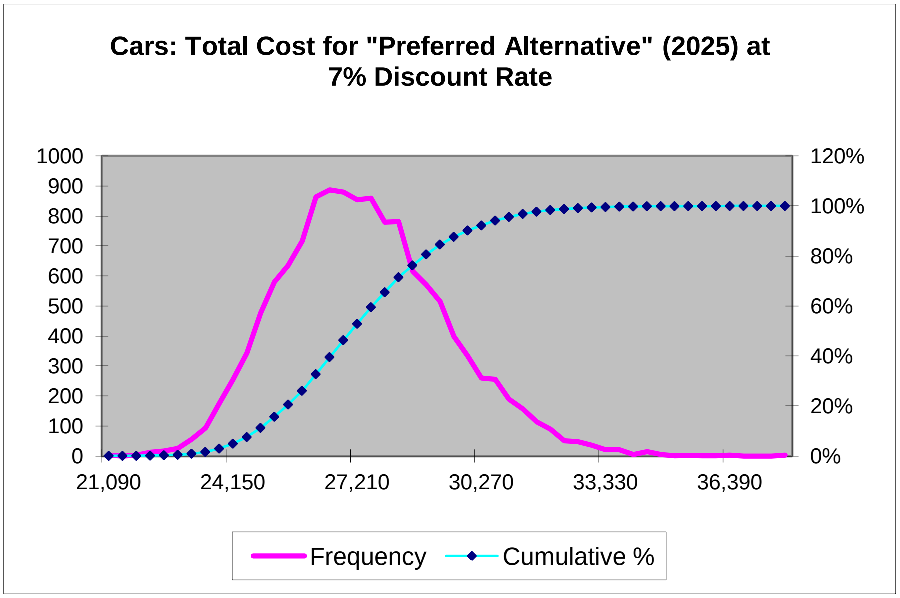
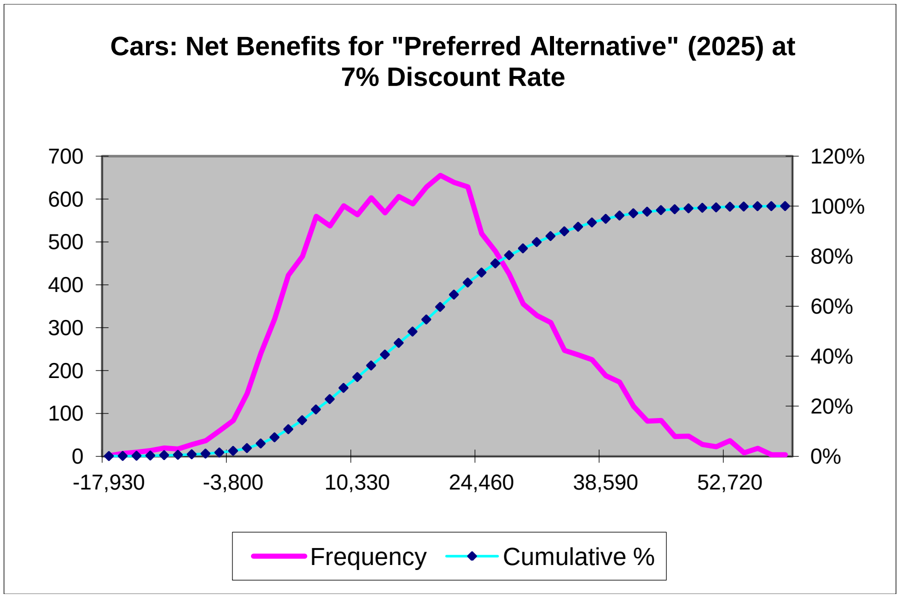


FIGURE XII-14
Model Output Profile



XIII. REGULATORY FLEXIBILITY ACT AND UNFUNDED MANDATES REFORM ACT ANALYSIS

A. Regulatory Flexibility Act

The Regulatory Flexibility Act of 1980 (5 U.S.C §601 et seq.) requires agencies to evaluate the potential effects of their proposed and final rules on small business, small organizations and small Government jurisdictions.

5 U.S.C §603 requires agencies to prepare and make available for public comments initial and final regulatory flexibility analysis (RFA) describing the impact of proposed and final rules on small entities. Section 603(b) of the Act specifies the content of a RFA. Each RFA must contain:

1. A description of the reasons why action by the agency is being considered;
2. A succinct statement of the objectives of, and legal basis for a final rule;
3. A description of and, where feasible, an estimate of the number of small entities to which the final rule will apply;
4. A description of the projected reporting, recording keeping and other compliance requirements of a final rule including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record;
5. An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap or conflict with the final rule;
6. Each final regulatory flexibility analysis shall also contain a description of any significant alternatives to the final rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities.

1. Description of the reason why action by the agency is being considered
NHTSA is proposing this action to improve vehicle fuel economy.

2. Objectives of, and legal basis for, the final rule
The Energy Independence and Security Act (EISA) mandates the setting of separate standards for passenger cars and for light trucks at levels sufficient to ensure that the average fuel economy of the combined fleet of all passenger cars and light trucks sold by all manufacturers in the U.S. in model year 2020 equals or exceeds 35 miles per gallon.

3. Description and estimate of the number of small entities to which the final rule will apply
The proposal will affect motor vehicle manufacturers. There are no light truck manufacturers that are small businesses. However, there are nine domestically owned small passenger car manufacturers.

Business entities are defined as small business using the North American Industry Classification System (NAICS) code, for the purpose of receiving Small Business Administration assistance. One of the criteria for determining size, as stated in 13 CFR 121.201, is the number of employees in the firm. For establishments primarily engaged in manufacturing or assembling automobiles, light and heavy duty trucks, buses, motor homes, or motor vehicle body manufacturing, the firm must have less than 1,000 employees to be classified as a small business.

We believe that the rulemaking would not have a significant economic impact on the small vehicle manufacturers because under Part 525, passenger car manufacturers making less than 10,000 vehicles per year can petition NHTSA to have alternative standards set for those manufacturers. Those manufacturers that currently don't meet the required levels for their footprint can petition the agency for relief. If the standard is raised, it has no meaningful impact on these manufacturers; they still must go through the same process and petition for relief. Other small manufacturers (Tesla and Fisker) make electric vehicles or hybrid vehicles that will pass the proposed rule.

Currently, there are nine small passenger car motor vehicle manufacturers in the United States. Table X1II-1 provides information about the 9 small domestic manufacturers in MY 2010. All are small manufacturers, having much less than 1,000 employees.

Table XIII-1
Small Vehicle Manufacturers

Manufacturer	Employees	Estimated Sales	Sale Price Range	Est. Revenues*
Carbon Motor[1]	NA	NA	NA	NA
CODA[2]	150	NA	$44,900**	NA
Fisker Automotive Inc.[3]	NA	15,000	$80,000	$1,200,000,000
Mosler Automotive	25	20	$189,000	$3,780,000
Panoz Auto Development Company	50	150	$90,000 to $125,000	$16,125,000
Saleen	170	1,000 16***	$39,000 to $59,000 $585,000	$144,355,000
Shelby American, Inc[4]	44	60	$42,000 to $135,000	$5,310,000
Standard Taxi[5]	35	80	$25,000	$2,000,000
Tesla Motors, Inc.	250	2,000	$50,000 to $100,000	$150,000,000

1. Designs, manufactures, and sells law enforcement patrol vehicles
2. Designs, manufactures, and sells electric vehicles; Vehicle launch are expected to start on December 2011
3. A joint venture of Quantum Fuel Systems Technologies Worldwide, Inc, and Fisker Coachbuild, LLC. The company is just starting. These are planned sales.
4. A division of Carroll Shelby International, Inc.
5. A subsidiary of Vehicle Production Group LLC (VPG). VPG has 35 employees.

* Assuming an average sales price from the sales price range

** Before the $8,000 federal tax credit and state incentives

*** Ford Mustang Conversions

The agency has not analyzed the impact of the proposal on these small manufacturers individually. However, assuming those that do not meet the final rule would petition the agency, rather than meet the final rule, the cost is not expected to be substantial.

<u>4. A description of the projected reporting, record keeping and other compliance requirements of a final rule including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record.</u>
This final rule includes no new requirements for reporting, record keeping of other compliance requirements.

<u>5. An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the final rule</u>
EPA and NHTSA are proposing joint rules which complement each other. We know of no other Federal rules which duplicate, overlap, or conflict with the final rule.

6. A description of any significant alternatives to the proposal which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities.

The agencies have analyzed 10 different alternative levels of fuel economy and have provided a number of flexibilities. However, there are no other alternatives that can achieve the stated objectives without installing fuel economy technologies into the vehicle that could significantly minimize the impact on small entities.

B. Unfunded Mandates Reform Act

Section 202 of the Unfunded Mandates Reform Act of 1995 (UMRA) requires Federal agencies to prepare a written assessment of the costs, benefits, and other effects of a proposed or final rule that includes a Federal mandate likely to result in the expenditure by State, local, or tribal governments, in the aggregate, or by the private sector, of more than $100 million in any one year (adjusted for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for 2009 results in $134 million (109.615/81.536 = 1.34). Before promulgating a rule for which a written statement is needed, section 205 of UMRA generally requires NHTSA to identify and consider a reasonable number of regulatory alternatives and adopt the least costly, most cost-effective, or least burdensome alternative that achieves the objectives of the rule. The provisions of section 205 do not apply when they are inconsistent with applicable law. Moreover, section 205 allows NHTSA to adopt an alternative other than the least costly, most cost-effective, or least burdensome alternative if the agency publishes with the final rule an explanation why that alternative was not adopted.

This proposal will not result in the expenditure by State, local, or tribal governments, in the aggregate, of more than $134 million annually, but it will result in the expenditure of that magnitude by vehicle manufacturers and/or their suppliers. NHTSA considered a variety of alternative average fuel economy standards lower and higher than those proposed, as well as proposed flexibilities for the manufacturers to comply with the proposal. NHTSA is statutorily required to set standards at the maximum feasible level achievable by manufacturers based on its consideration and balancing of relevant factors and has concluded that the proposed fuel economy standards are the maximum feasible standards for the passenger car and light truck fleets for MYs 2017-2025 in light of the statutory considerations.